L005P12002

B10

(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 1 418 776 A1

(12) EUROPEAN PATENT APPLICATION

(43) Date of publication:
12.05.2004 Bulletin 2004/20

(51) Int Cl.7: H04Q 7/36

(21) Application number: 03078518.2

(22) Date of filing: 07.11.2003

(84) Designated Contracting States:
AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HU IE IT LI LU MC NL PT RO SE SI SK TR
Designated Extension States:
AL LT LV MK

(30) Priority: 07.11.2002 KR 2002068830
29.10.2003 KR 2003075845

(71) Applicant: SAMSUNG ELECTRONICS CO., LTD.
Suwon-City, Kyungki-do (KR)

(72) Inventors:
- Hwang, Chan-Soo
Samsung Electronics Co., Ltd.
Suwon-city Kyungki-do (KR)
- Kim, Ki-Ho Samsung Electronics Co., Ltd.
Suwon-city Kyungki-do (KR)
- Kim, Young-Soo Samsung Electronics Co., Ltd.
Suwon-city Kyungki-do (KR)
- Park, Won-Hyong Samsung Electronics Co., Ltd.
Suwon-city Kyungki-do (KR)
- Yun, Sang-Boh Samsung Electronics Co., Ltd.
Suwon-city Kyungki-do (KR)

(74) Representative: Mertens, Hans Victor
Exter Polak & Charlouis B.V., P.O. Box 3241
2280 GE Rijswijk (NL)

(54) Frequency reuse method in an orthogonal frequency division multiplex mobile communication system (OFDM)

(57) A frequency reuse method in an OFDM mobile communication system is provided. Frequency resources available to each BS are divided into at least four frequency groups and a different or the same frequency reuse distance is set for each of the frequency groups. The frequency groups are sequentially assigned to cell areas of each BS such that lower frequency groups are available to a near cell area and higher frequency resource groups are available to a remote cell area.

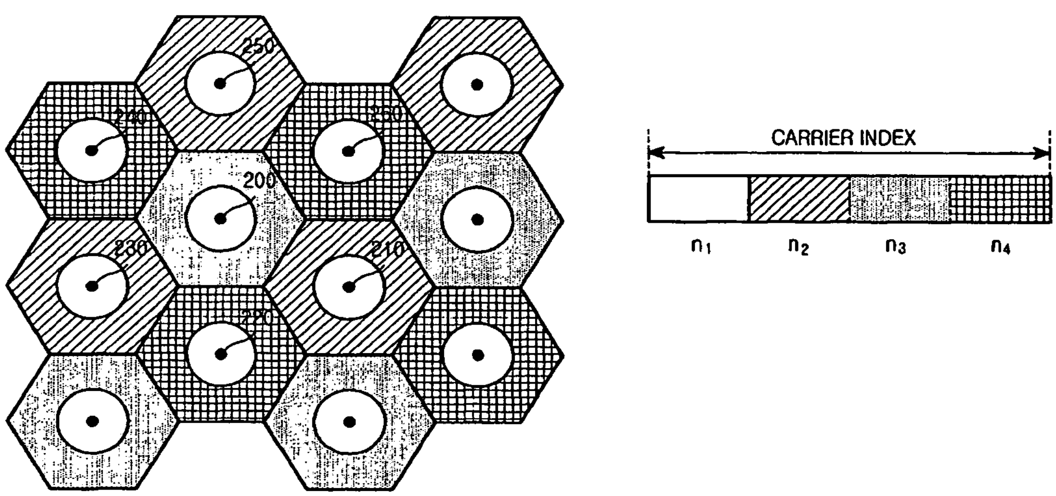


FIG.2

EP 1 418 776 A1

Description

[0001] The present invention relates generally to a frequency reuse method in a mobile communication system, and in particular, to a frequency reuse method in an orthogonal frequency division multiplex (OFDM) mobile communication system.

[0002] Mobile communication systems are designed to provide voice service, ensuring mobility for users. Owing to the drastic development of mobile communication technology and ever-increasing user demands, these mobile communication systems have been developed to additionally provide data service. Data transmission has been evolved from short messages to Internet service. Today, high-rate data transmission such as moving pictures is possible. Transmission schemes, developed from traditional cellular systems, are now under discussion for standardization in the 3rd generation partnership project (3GPP). The 3G mobile communication systems are categorized into synchronous code division multiple access (CDMA) and asynchronous CDMA.

[0003] OFDM is a type of multi-carrier modulation. OFDM spread spectrum technology distributes data over multiple carriers spaced from each other with respect to a central frequency, thereby offering orthogonality between the carriers. The OFDM has excellent performance in a multi-path radio environment. For this reason, the OFDM attracts much interest as a suitable modulation scheme for digital terrestrial television service and digital audio broadcasting. Hence it is expected that the OFDM will be adopted as a digital television standard in Europe, Japan, and Australia and is currently envisioned for use in a fourth generation mobile communications system.

[0004] For mobile communication applications, the OFDM has the following advantages.

(1) The duration of a single transmission symbol is a multiple of the number of carriers, as compared to a single carrier scheme. If a guard interval is added, multi-path-caused transmission characteristic deterioration can be decreased.

(2) In view of data distribution across the entire frequency band, the influence of interference in a particular frequency is limited to a limited number of data bits, and errors can be reduced by interleaving and error correction codes.

(3) OFDM modulation waves are almost random noise. Thus, their effects on different services are equivalent to the influence of random noise.

(4) The OFDM allows fast Fourier transform (FFT)-based modulation/demodulation.

[0005] Because of the above-described and other benefits, many studies are being actively conducted on the OFDM.

[0006] However, one base station (BS) can not use all of the available OFDM frequency channels in view of the orthogonality of frequencies used. If a total of 512 frequency channels are available and 4 or 32 frequency channels, here 4 frequency channels are assigned to one user, up to 128 resources are available to a BS.

In the case where each BS is allowed to use the 128 resources, the same frequency resources may be used in different BSs. Supposing that there are BS A and BS B adjacent to BS A, both BSs may assign the same 4 channels to mobile stations (MSs) within their cells. If the MSs are near to each other, they experience deterioration of carrier-to-interference ratio (C/I) characteristics.

[0007] To solve the problem, each BS adaptively assigns carriers according to interference. The BS assigns a higher priority to an unused frequency in an adjacent BS. It further prioritizes frequencies used in adjacent BSs according to distances between MSs within its cell and those within the adjacent cells. The BS assigns higher-priority frequencies before lower-priority ones.

[0008] To make this scheme viable, the BS must predetermine the frequencies that adjacent BSs are using and calculate the distances between an MS being serviced within its cell and MSs being serviced within the adjacent cells. As a result, system complexity is increased.

[0009] To avoid the constraints, cellular systems implement frequency reuse. Fig. 1 illustrates a conventional frequency reuse scheme with a frequency reuse distance of 3 in an OFDM cellular mobile communication system.

[0010] Referring to Fig. 1, a complete frequency bandwidth is partitioned into three parts. A third of the bandwidth is available to each BS so that each of BSs 110 to 160 uses a different frequency from those of its adjacent BSs. For example, BS 100 uses a third of the carrier indexes and its adjacent BSs 120 to 160 use the other two thirds of carrier indexes. Similar system design occurs at the other BSs. Here, the frequency reuse distance is 3. In general, cellular systems implement frequency reuse with a longer frequency distance based on this principle.

[0011] Despite the advantage of efficient and non-overlapped frequency use, the above conventional frequency reuse scheme has the distinctive shortcoming that the entire frequency bandwidth cannot be fully utilized in each cell. The number of channels available to a particular BS is the number of serviceable users or the data rates of services. Therefore, the decrease of the number of available channels limits the number of serviceable users or the data rates.

[0012] It is, therefore, an object of the present invention to provide a method of increasing frequency reuse in an OFDM mobile communication system.

[0013] It is another object of the present invention to provide a method of increasing frequency reuse without affecting the data performance of users in an OFDM mobile communication system.

[0014] It is a further object of the present invention to provide a method of increasing the availability of frequency resources in an OFDM mobile communication system.

[0015] The above objects are achieved by a frequency reuse method in an OFDM mobile communication system. Frequency resources available to each BS are divided into at least four frequency groups and a frequency reuse distance is set for each of the frequency groups. The frequency reuse distance set for each of the frequency group can be the same or different. The frequency groups are sequentially assigned to cell areas of each BS such that lower frequency groups are available to a near cell area and higher frequency resource groups are available to a remote cell area.

[0016] Each of the frequency groups includes successive carriers. When frequency hopping is adopted, the frequency resources are divided into the at least four frequency groups according to frequency hopping patterns. At least one of the frequency groups is used with a frequency reuse distance of 1 in the near cell area. The near cell area is defined according to one of the distance from the BS, a system-required carrier-to-interference ratio (C/I), or interference from an adjacent BS. The at least four frequency groups are of the same size.

[0017] To assign frequency resources to MSs in an OFDM mobile communication system, a BS, having first frequency resources for a near cell area and second frequency resources for a remote cell area, determines one of the distance between the BS and an MS, received signal strength, or interference from an adjacent BS, upon request of the MS for OFDM frequency setup. If a predetermined condition is satisfied, the BS establishes a channel with the MS by assigning a first OFDM frequency resource to the MS. If the MS is outside of the near cell area, the BS establishes a channel with the MS by assigning a second OFDM frequency resource to the MS.

[0018] To assign OFDM frequency resources to MSs in an OFDM system having a plurality of BSs, each BS communicating with MSs in OFDM, having at least two sub-channel groups, and assigning OFDM frequency resources to an MS requesting a communication, the BS compares the SIR of an MS with a predetermined reference SIR, upon request for an OFDM frequency setup from the MS, and assigns OFDM frequency resources in a low sub-channel group to the MS if the SIR of the MS is lower than the reference SIR.

[0019] If at least three sub-channel groups are set and at least two predetermined reference SIRs are used to discriminate the sub-channel groups, the BS assigns to the MS OFDM frequency resources in a sub-channel group corresponding to the lowest of reference SIRs higher than the SIR of the MS.

[0020] The sub-channel group for the MS is determined according to the SIR and lognormal fading-including signal loss of the MS.

[0021] The above and other objects, features and advantages of the present invention will become more apparent from the following detailed description when taken in conjunction with the accompanying drawings in which:

Fig. 1 illustrates clusters of cells with a frequency reuse distance of 3 according to a conventional frequency reuse scheme in an OFDM cellular mobile communication system;

Fig. 2 illustrates clusters of cells with two frequency reuse distances of 1 and 3 in an OFDM mobile communication system according to an embodiment of the present invention;

Fig. 3 illustrates distance-based division of a cell area into a near area and a remote area according to the present invention;

Fig. 4 is a graph illustrating block probability given by an Erlang B formula;

Fig. 5 illustrates C/I or signal strength-based division of a cell area into a near area and a remote area according to the present invention;

Fig. 6 illustrates clusters of cells with two frequency reuse distances of 1 and 3 in an OFDM mobile communication system adopting frequency hopping according to another embodiment of the present invention;

Fig. 7 illustrates a method of assigning sub-channels to users according to a third embodiment of the present invention;

Fig. 8 illustrates a mesh plot of SIRs at the edges of an inner cell and an outer cell under a load of 50%; and

Fig. 9 illustrates a contour plot of the SIRs at the edges of the inner cell and the outer cell under the load of 50%.

[0022] Preferred embodiments of the present invention will be described herein below with reference to the accompanying drawings. In the following description, well-known functions or constructions are not described in detail since they would obscure the invention in unnecessary detail.

[0023] It is to be appreciated that while frequency reuse is implemented using two frequency reuse distances of 1 and 3 in the following description of the present invention, the number of frequency reuse distances is not limited. In fact, an OFDM frequency reuse distance can be 3, 4, 7, ... In addition, although hexagonal-shaped cells are artificial and such a shape cannot be generated in the real world, that is, each BS has a different shape of cell coverage, the ideal hexagonal cell shapes are assumed herein.

[0024] Fig. 2 illustrates a frequency reuse scheme in an OFDM mobile communication system according to an embodiment of the present invention.

[0025] Referring to Fig. 2, a given frequency bandwidth is partitioned into four carrier index groups n_1 to n_4 in order to obtain two frequency reuse distances of 3 and 1. If any other frequency reuse distances are adopted, the frequency bandwidth is partitioned into more or less parts. The reason for using the two frequency reuse distances is to achieve a satisfactory C/I at cell borders or cell edges when the frequency reuse distance of 3 is used. As the system requires a higher C/I level, or propagation loss and fading variance are great, a greater frequency reuse distance, should be used. In other words, the frequency reuse distance is varied according to the configuration of the BSs (i.e., propagation distance, propagation losses, fading variance, system-required C/I, and distance between BS and MS).

[0026] A different frequency reuse distance is used according to the distance from a BS. OFDM carriers are assigned with a frequency reuse distance of 1 in a near cell area and with a frequency reuse distance of 3 in a remote cell area. The cell area can be divided according to C/I instead of the distance. In this case, the cell area is divided into a good channel-condition area and a bad channel-condition area. Since the C/I varies with the layout of buildings and the type of geographic terrain contour, the shapes of cell area coverages are different, which will be described later with reference to Fig. 5.

[0027] The frequencies of carrier index group n_1 are used in an area apart from each BS by a predetermined distance or less with a frequency reuse distance of 1. The areas are called "near areas (inner cells)" which are circular with respect to the BSs 200 to 260. The remaining areas are called "remote areas (outer cells)." MSs within the near areas generally have good C/I characteristics. The distinction between the near areas and the remote areas can be made by system-required C/I and interference from adjacent BSs, instead of distance.

[0028] Fig. 3 illustrates a cell which is divided into a near area and a remote area according to distance from a BS in the present invention. Referring to Fig. 3, the cell 200a of the BS 200 covers its signal propagation distance. The cell coverage is divided into a near area 200b with a radius r that is changed according to the characteristics and geographical features of the BS 200. The remaining area outside of the near area 2006 of the cell coverage is defined as a remote area. There is little interference from adjacent BSs within the near area 200b. Thus, application of the frequency reuse distance of 1 to the near area 200b does not affect MSs within other cells.

[0029] Returning to Fig. 2, OFDM frequencies are reused in the remote areas as done in the conventional frequency reuse scheme. As stated before, since hexagonal cells are assumed, OFDM frequencies are assigned to the remote areas of the BSs 200 to 260 without overlapped areas. With a frequency reuse distance of 3, the carrier index groups n_2, n_3 and n_4 are available to BSs 200 to 260. Thus, each BS assigns a channel to an MS in its remote area within resources assigned to the BS. For example, if the carrier index group n_2 is available to BS 200, BS 200 assigns a channel within the available frequency band to an MS in its remote area.

[0030] If the MS is located in the near area of BS 200, BS 200 assigns a channel within the carrier index group n_1 to the MS. The same situation occurs within the other BSs all converge areas. That is, if the carrier index group n_3 is available to BS 210, the BS 210 assigns a channel in the carrier index group n_1 to an MS in its near area and a channel in the carrier index group n_3 to an MS in its remote area, as illustrated in Fig. 2.

[0031] Fig. 5 illustrates a cell that is divided into a near area and a remote area according to signal strength or C/I in the present invention. The distance-based near area 200b and a C/I-based near area 200C have different borders due to the channel condition between BS 200 and an MS, propagation loss, and the geographical features. While not shown, cell coverage 200a is also different in the real world for the same reason. For clarity of description, the near and remote areas are defined according to the distance from the BSs and the following description is also based on this assumption, even though the near and remote areas have different shapes depending on various factors.

[0032] In accordance with the first embodiment of the present invention, the complete frequency bandwidth is partitioned into a predetermined number of carrier index groups. One of the carrier index groups is used with a frequency reuse distance of 1 and the other carrier index groups, with a frequency reuse distance of 3. In case of non-hexagonal-shaped cell coverage, a frequency reuse distance higher than 3 should be used. Then the complete spectrum available is partitioned into (frequency reuse distance +1) parts. While the frequency bandwidth is equally partitioned in this embodiment, the divided carrier index groups may have different sizes considering the geographical features of the cells.

[0033] Fig. 6 illustrates clusters of cells with frequency reuse distances of 1 and 3 in an OFDM mobile communication system using frequency hopping according to another embodiment of the present invention.

[0034] While the complete spectrum is partitioned into the carrier index group n_1 for a frequency reuse distance of 1 and the carrier index groups n_2, n_3 and n_4 for a frequency reuse distance of 3 and each carrier index group has successive carriers in the first embodiment, each carrier index group consists of discontinuous carriers in the second embodiment.

[0035] Referring to Fig. 6, to improve frequency diversity, the complete spectrum is partitioned into three carrier index groups, G1, G2 and G3. Each carrier index group includes carriers spaced from each other by a predetermined bandwidth. In the OFDM system using orthogonal frequency hopping, the carrier index groups G1, G2 and G3 are formed

according to frequency hopping patterns. Using these carrier groups, different frequency reuse distances are achieved. The carrier group G1 is used in the near areas of BSs 200 to 260 with a frequency reuse distance of 1 and the carrier groups G1, G2 and G3 are used in the remote areas with a frequency reuse distance of 3. The use of frequency hopping effects interference averaging. Therefore, the near areas with the frequency reuse distance of 1 can be widened. As stated before, the near areas are defined according to the distance from the BS or system-required C/I.

[0036] Now a description will be made of deriving a cost function on the following suppositions to implement the present invention in an optimizing way.

1. Users are distributed uniformly across a cell and the number of users is determined by an average Poisson process.
2. Cell radius is standardized to 1. A user in a near area with a radius r satisfies system-required frame error rate (FER) even if a frequency reuse distance is set to 1. A user apart from the BS by a distance between r and 1 satisfies the FER requirement when the frequency reuse distance is 3. All cells are of circular shapes. In this case, the average number of users in the near area is r^2 and that of users outside the near area is $1-r^2$. These are identified as separate Poisson processes.
3. If a total of N OFDM carriers are available and M carriers are assigned to each user, the number of available resources is n(=N/M). For an area with a frequency reuse distance of 1, n_1 resources are used and for an area with a frequency reuse distance of 3, n_2 resources are used. Then, $n=n_1+3n_2$. To optimize n_1 and n_2, the sum of blocking rates is used as the cost function.
4. If no buffers are used in the OFDM system, n_1 servers and n_2 servers are required and traffic generations rates for n_1 and n_2 are R^2 and $(1-R^2)$, respectively.

[0037] On the above suppositions, the blocking probability is given by a known Erlang B formula, expressed as

$$\text{Minimize} \quad \left\{ \frac{\dfrac{\lambda_1^{n_1}}{n_1!}}{\sum_{j=0}^{n_1} \dfrac{\lambda_1^{j}}{j!}} + \frac{\dfrac{\lambda_2^{n_2}}{n_2!}}{\sum_{j=0}^{n_2} \dfrac{\lambda_2^{j}}{j!}} \right\} \qquad \ldots\ldots (1)$$

where n_1 and n_2 are the numbers of resources available to the near area and remote area, respectively. n_1 and n_2 are in the relation that $n=n_1+3n_2$. Here, n_1 and n_2 are integers. λ_1 and λ_2 are the probabilities of generating any event in the near area and the remote area, respectively. j is a parameter for summation, ranging from 1 to n_1 or from 0 to n_2.

[0038] The Erlang B formula is represented as a graph illustrated in Fig. 4. Referring to Fig. 4, the blocking probability is always positive and the graph is given as a downwards convex parabola. Therefore, the cost is minimized at the apex of the parabola (i.e., zero differential of the cost function).

[0039] The use of the single frequency reuse distance 1 will be compared with the use of the different frequency reuse distances 1 and 3 in combination.

[0040] The blocking probability for the frequency reuse distance of 3 is

$$\frac{\lambda^{n/3}}{(n/3)!} \bigg/ \sum_{j=0}^{n/3} \frac{\lambda^j}{j!} \qquad \ldots..(2)$$

[0041] In accordance with the present invention, n channels are divided into a greater number of sub-channels than in the conventional frequency reuse scheme by further defining an area with the frequency reuse distance of 1. As a result, the number of channels available specifically to each BS is decreased. Yet, if the frequency bandwidth (except the carriers) available commonly to all BSs is partitioned into three parts, n_1+n_2 frequencies are eventually available to each BS. Hence, the total number of carriers available to each BS is increased in effect. This was simulated as follows.

[0042] The total number of OFDM frequencies is 512 and 4 or 32 channels are available to one user. The total number of available resources is then 128. System load is the ratio of traffic generated per unit time to the total number of available channels. If r is between 0.3 and 0.4 for the frequency reuse distance of 1, the blocking probability is less than that when the frequency reuse distance is 3. If r is increased to 0.9 and the blocking probability is fixed to 0.02, the BS capacity is four times greater than that when the frequency reuse distance is 3.

[0043] Frequency resources are assigned to an MS according to one of the distance between the MS and a BS, received signal strength, or interference from adjacent BSs. While the given bandwidth is partitioned into (frequency reuse distance +1) parts, it can be partitioned into more parts. In addition, while the frequency resources are classified into two types, it is obvious that they can be divided into more types.

[0044] As described before, when the frequency resources are classified into two types, frequencies in different carrier groups are assigned to an MS in a near area and an MS in a remote area, respectively.

[0045] The frequency resources of two types can be assigned to MSs according to received signal strength, or interference from other adjacent BSs. In the case where the frequency resources are classified into more types, MSs are sorted according to the above criteria and the frequency resources are assigned correspondingly.

[0046] Only the distance between a BS and an MS is considered in the above sub-channel assignment. In a real environment, however, it is preferable to assign a sub-channel group with a relatively low load to a user experiencing the greatest path loss involving lognormal fading. Alternatively, if the SIRs (Signal-to-Interference Ratios) of users are known, it is also preferable to assign a sub-channel with a relatively low load to a user having the lowest SIR. On the assumption that sub-channels are divided into a small path loss group and a great path loss group, sub-channels are assigned to users according to a predetermined reference SIR and the SIRs of the users.

[0047] In the case of three sub-channel groups, two or more predetermined reference SIRs are needed to distinguish the sub-channel groups. In this case, OFDM frequency resources in a sub-channel group having the lowest of reference SIRs higher than the SIR of an MS are assigned to the MS.

[0048] Hereinbelow, a description is made of a method of assigning sub-channels according to path loss involving lognormal fading and a method of assigning sub-channels according to the SIRs of users.

[0049] In general, since an MS near to a BS is remote from adjacent cells, the resulting low signal interference leads to a sufficiently high SIR. In this case, even if traffic load is great, the MS has a substantially low error rate. However, as the MS moves farther from the BS, the channel interference from the adjacent cells increases, resulting in a lower SIR. Therefore, the interference should be reduced for the MS.

[0050] For the purpose, sub-channels are divided into two or more groups relying on the above principle in the present invention. The SIR is improved by assigning sub-channels according to traffic load, instead of distance. Hence, the respective sub-channel groups are assigned to users having different traffic loads, which will be described with reference to Fig. 7. Fig. 7 is a view illustrating a sub-channel assigning method according to a third embodiment of the present invention.

[0051] Referring to Fig. 7, the BS is divided into the inner cell 200b and the outer cell 200a. The area division is made according to traffic load, not distance even though the division criterion is shown to be distance due to representational difficulty. In reality, the inner and outer cells can be defined considering distance additionally. Available sub-channels (carriers) are divided into two different groups n_1 and n_2. Frequencies within the frequency group n_2 are assigned to MSs 301 to 304 in the outer cell 200a by frequency hopping 320. Similarly, frequencies within the frequency group n_1 are assigned to MSs 311, 312 and 313 in the inner cell 200b by the frequency hopping 320.

[0052] While two sub-channel groups have been set according to traffic load for notational simplicity, the number of

sub-channel groups can be 3 or more. Use of an appropriate number of sub-channel groups according to system environment improves efficiency.

[0053] The loads of n_1 and n_2 are controlled by adjusting the number of sub-channels in the respective sub-channel groups. If each sub-channel group has the same number of sub-channels, the load can be controlled by changing the number of users supported by the sub-channel group. In the case of a high average traffic, an optimum load for a high-load sub-channel group is about 1.0. When adjusting the load, the lowest of the SIRs of users using the high-load sub-channel group should be equal to or higher than the lowest of the SIRs of users using the low-load sub-channel group.

[0054] A channel model for the load-based sub-channel assignment and its efficiency will now be described below.

[0055] r is a value obtained by dividing the distance between a BS and an MS by the half of the distance between the cell of the BS and its adjacent cell. And a channel between the BS and the MS is modeled as

$$\Gamma(d) = \frac{c}{d^{\alpha}} \qquad (3)$$

where d is the distance between the BS and the MS and c is a constant determined by a frequency and an environment, and α is a path loss exponent. If α is 2, the channel model is equivalent to a free space model. The SIR of an MS spaced from the BS by r is expressed as

$$\frac{1/r^{\alpha}}{2p\left[\left(\frac{1}{\sqrt{3}-r}\right)^{\alpha}+\left(\frac{1}{3+r^{2}-\sqrt{3}r}\right)^{\alpha}+\left(\frac{1}{3+r^{2}+\sqrt{3}r}\right)^{\alpha}\right]} \quad \ldots\ldots (4)$$

[0056] On the assumption of a circular cell, the average of packets generated is proportional to area, and the load of the cell is p, r^2N_P packets are generated within a circle spaced from the BS by a normalized distance as the radius of the circle, r and $(1-r^2)N_P$ packets are generated outside the circle. Here, a target SIR is s.

[0057] Now, sub-channels must be arranged in the manner that maximizes p. If N sub-channels are available, N_1 sub-channels are assigned to users spaced from the BS by r or below and N_2 sub-channels are assigned to users spaced from the BS by a distance longer than r. Then, the loads are r^2N_P/N_1 and $(1-r^2)N_P/N_2$, respectively. Computation of SIRs at the edges of the inner cell and the outer cell by Eq. (4) is represented as

$$\frac{1}{\frac{2p(1-r^{2})N}{N-N_{1}}\left[\left(\frac{1}{\sqrt{3}-1}\right)^{\alpha}+\left(\frac{1}{4-\sqrt{3}}\right)^{\alpha}+\left(\frac{1}{4+\sqrt{3}}\right)^{\alpha}\right]} \quad \ldots\ldots (5)$$

$$\frac{1/r^{\alpha}}{\frac{2pr^{2}N}{N_{1}}\left[\left(\frac{1}{\sqrt{3}-r}\right)^{\alpha}+\left(\frac{1}{3+r^{2}-\sqrt{3}r}\right)^{\alpha}+\left(\frac{1}{3+r^{2}+\sqrt{3}r}\right)^{\alpha}\right]} \quad \ldots\ldots (6)$$

[0058] Therefore, a maximum cell load p higher than the target SIR s, calculated by Eq. (5) and Eq. (6), is a maximum

system capacity. On the other hand, with p given, r and N, are determined such that values calculated by Eq. (5) and Eq. (6) are minimized and thus a minimum SIR is obtained. That is, optimization can be carried out in two ways.

[0059] In view of non-linearity of Eq. (5) and Eq. (6) with respect to r and N_1, the optimization is done graphically. For example, with α fixed to 4 and r and N_1/N used as variables, SIR is graphed as illustrated in Figs. 8 and 9. Fig. 8 illustrates a mesh plot of SIRs at the edges of the inner cell and the outer cell when the loads are 50% and Fig. 9 illustrates a contour plot of the SIRs at the edges of the inner cell and the outer cell when the loads are 50%.

[0060] Referring to Fig. 8, an x axis represents the quotient of dividing the distance between a BS and an MS by the distance between the BS and the remotest MS, a y axis represents the quotient of dividing the number of sub-channels assigned to a high-load frequency hopping group by the number of entire sub-channels, and a z axis represents SIR. The SIR at the highest point of a curve 400 is 50dB and the SIR at the lowest point of the curve 40 is -20dB.

[0061] Referring to Fig. 9, an x axis represents the quotient of dividing the distance between a BS and an MS by the distance between the BS and the remotest MS, and a y axis represents the quotient of dividing the number of sub-channels assigned to a high-load frequency hopping group by the number of entire sub-channels. The SIR of a curve 500 nearest to the origin is 50dB, and the SIR of a curve 510 remotest from the origin is -5dB. SIR gain changes with respect of the change of an average load as illustrated from Figs. 8 and 9 are tabulated below.

(Table 1)

Load	Previous SIR	Current SIR	Gain	r	N_1/N	Inner load
0.7	-7dB	-3.85dB	3.15dB	0.885	0.565	0.97
0.5	-5.5dB	-2.15dB	3.35dB	0.885	0.415	0.88
0.3	-3.3dB	0.08dB	3.4dB	0.83	0.32	0.65
0.1	1.45dB	4.dB	3.1dB	0.84	0.33	0.21

[0062] In Table 1, Load is an overall average load, Previous SIR is an SIR at a cell edge when the inventive sub-channel assignment is not applied, and Current SIR is an SIR at the cell edge when the inventive sub-channel assignment is applied. Gain is the difference between Previous SIR and Current SIR, and r is a value obtained by dividing the distance between a BS and an MS by the half of the distance between cells. N_1/N is obtained by dividing the number of sub-channels assigned to a high-load area by the number of entire sub-channels. Inner load inner the load of a high-load area (in general, the load of a frequency hopping group assigned to a user within a cell). As noted from Table 1, the inventive sub-channel assignment brings an SIR gain of about 3dB.

[0063] In accordance with the present invention, OFDM frequencies are partitioned into a predetermined number of parts and each cell is divided into a near area and a remote area. For the near area, a frequency reuse distance of 1 is used and for the remote area, a different frequency reuse distance is used. When frequency hopping is adopted, frequencies are reused in the same manner except that each divided carrier index group has discontinuous carriers. Consequently, frequency utilization is increased.

[0064] While the invention has been shown and described with reference to certain preferred embodiments thereof, it will be understood by those skilled in the art that various changes in form and details may be made therein without departing from the scope of the invention as defined by the appended claims.

Claims

1. Frequency reuse method in an orthogonal frequency division multiplex (OFDM) mobile communication system having a plurality of base stations (BS), comprising the steps of:

    dividing frequency resources available to each BS into at least four frequency groups and setting a frequency distance for each of the frequency groups; and
    sequentially assigning the frequency groups to cell areas of each BS such that lower frequency groups are available to a near cell area and higher frequency resource groups are available to a remote cell area.

2. Method according to claim 1, wherein each of the frequency groups includes successive carriers.

3. Method according to claim 1, wherein when frequency hopping is adopted, the frequency resources are divided into the at least four frequency groups according to frequency hopping patterns.

4. Method according to claim 1, wherein at least one of the frequency groups is used with a frequency reuse distance of 1 in the near cell area.

5. Method according to claim 4, wherein the near cell area is defined according to a distance from the BS.

6. Method according to claim 4, wherein the near cell area is defined according to a system-required carrier-to-interference ratio (C/I).

7. Method according to claim 7, wherein the near cell area is defined according to interference from an adjacent BS.

8. Method according to claim 1, wherein the at least four frequency groups are of the same size.

9. Method according to claim 1, wherein a frequency group assigned to the near cell area satisfies

$$\mathit{Minimize}\quad \left\{ \frac{\dfrac{\lambda_1^{\,n_1}}{n_1!}}{\sum_{j=0}^{n_1} \dfrac{\lambda_1^{\,j}}{j!}} + \frac{\dfrac{\lambda_2^{\,n_2}}{n_2!}}{\sum_{j=0}^{n_2} \dfrac{\lambda_2^{\,j}}{j!}} \right\}$$

where n_1 and n_2 are the numbers of frequency resources available to the near cell area and the remote cell area, respectively, λ_1 and λ_2 are the probabilities of generating an event in the near area and the remote area, respectively, and j is a parameter for summation.

10. Method according to claim 9, wherein the other frequency groups are of the same size and assigned to the remote cell area.

11. Frequency reuse method in an orthogonal frequency division multiplex (OFDM) mobile communication system having a plurality of base stations (BS), comprising the steps of:

dividing frequency resources into at least four frequency groups;
assigning a predetermined one of the frequency groups to a near cell area of each BS; and
assigning the other three frequency groups with a frequency reuse distance of 3 to a remote cell area of each BS.

12. Method of assigning frequency resources to mobile stations (MSs) in a base station (BS) having first frequency resources for a near cell area and second frequency resources for a remote cell area in an orthogonal frequency division multiplex (OFDM) mobile communication system, the method comprising the steps of:

determining a predetermined condition between the BS and an MS upon request of the MS for OFDM frequency setup;
establishing a channel with the MS by assigning a first OFDM frequency resource to the MS if the predetermined condition is satisfied; and
establishing a channel with the MS by assigning a second OFDM frequency resource to the MS if the MS is outside of the near cell area.

13. Method according to claim 12, wherein the predetermined condition is the distance between the BS and the MS.

14. Method according to claim 12, wherein the predetermined condition is the level of interference experienced by the MS from an adjacent BS

15. Method according to claim 12, wherein the predetermined condition is the strength of a received signal between

the MS and the BS.

16. Method according to claim 12, wherein the first frequency resources are used with a frequency reuse distance of 1 in the near cell area.

17. Method of assigning orthogonal frequency division multiplex (OFDM) frequency resources to mobile stations (MSs) in a base station (BS) in an OFDM system having a plurality of BSs, each BS communicating with MSs in OFDM, having at least two sub-channel groups, and assigning OFDM frequency resources to an MS requesting a communication, the method comprising the steps of:

    comparing the signal to interference ratio (SIR) of an MS with a predetermined reference SIR, upon request for an OFDM frequency setup from the MS; and
    assigning OFDM frequency resources in a low sub-channel group to the MS if the SIR of the MS is lower than the reference SIR.

18. Method according to claim 17, wherein if at least three sub-channel groups are set and at least two predetermined reference SIRs are used to discriminate the sub-channel groups, OFDM frequency resources in a sub-channel group corresponding to the lowest of reference SIRs higher than the SIR of the MS are assigned to the MS.

19. Method according to claim 17, wherein the sub-channel group for the MS is determined according to the SIR and lognormal fading-including signal loss of the MS.

20. Method according to claim 19, wherein a low-load sub-channel group is assigned to the MS if the MS has a great lognormal fading value.

21. Method according to claim 17, wherein the BS hops OFDM frequencies in the sub-channel group for the MS during communication with the MS according to a preset frequency hopping rule.

22. Method of assigning orthogonal frequency division multiplex (OFDM) frequency resources to mobile stations (MSs) in a base station (BS) in an OFDM system having a plurality of BSs, each BS communicating with MSs in OFDM, having at least two sub-channel groups, and assigning OFDM frequency resources to an MS requesting a communication, the method comprising the steps of:

    assigning, upon request for an OFDM frequency setup from an MS, to the MS OFDM frequency resources in a sub-channel group that maximizes load p in Eq. (10) and Eq. (11), when a channel is modeled as Eq. (8) and the average signal to interference ratio (SIR) of an MS spaced from the BS by a distance r is calculated by Eq. (9),

$$\Gamma(d) = \frac{c}{d^{\beta}} \tag{8}$$

$$\frac{1/r^{\alpha}}{2p\left[\left(\frac{1}{\sqrt{3}-r}\right)^{\alpha}+\left(\frac{1}{3+r^{2}-\sqrt{3}r}\right)^{\alpha}+\left(\frac{1}{3+r^{2}+\sqrt{3}r}\right)^{\alpha}\right]} \quad \ldots\ldots (9)$$

$$\frac{1}{\frac{2p(1-r^2)N}{N-N_1}\left[\left(\frac{1}{\sqrt{3}-1}\right)^{\alpha}+\left(\frac{1}{4-\sqrt{3}}\right)^{\alpha}+\left(\frac{1}{4+\sqrt{3}}\right)^{\alpha}\right]} \quad \ldots\ldots(10)$$

$$\frac{1/r^{\alpha}}{\frac{2pr^2N}{N_1}\left[\left(\frac{1}{\sqrt{3}-r}\right)^{\alpha}+\left(\frac{1}{3+r^2-\sqrt{3}r}\right)^{\alpha}+\left(\frac{1}{3+r^2+\sqrt{3}r}\right)^{\alpha}\right]} \quad \ldots\ldots(11)$$

where d is the distance between the BS and the MS, c is a constant determined by a frequency and an environment, α is a path loss exponent, a cell load is p, N is the number of entire sub-channels, and N_1 is the number of sub-channels assigned to an inner cell.

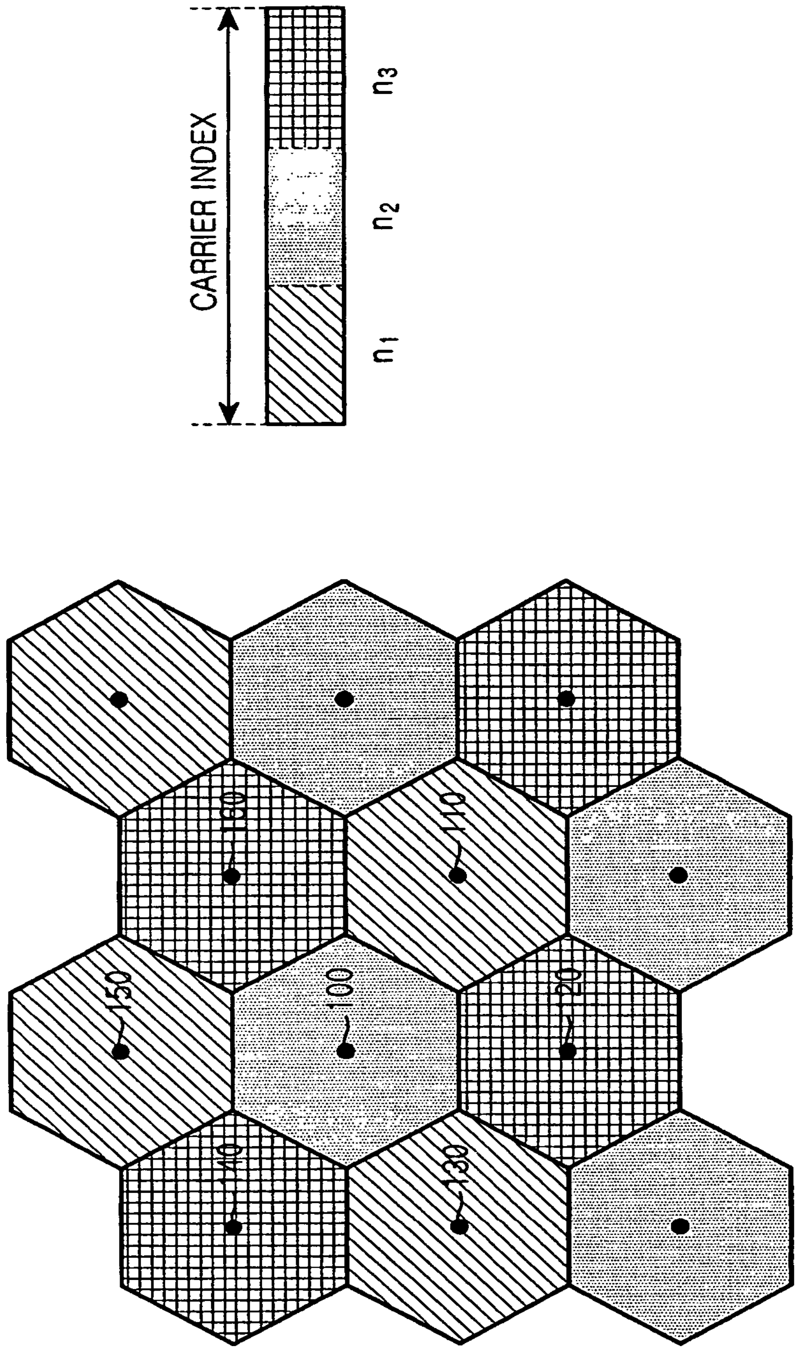


FIG. 1

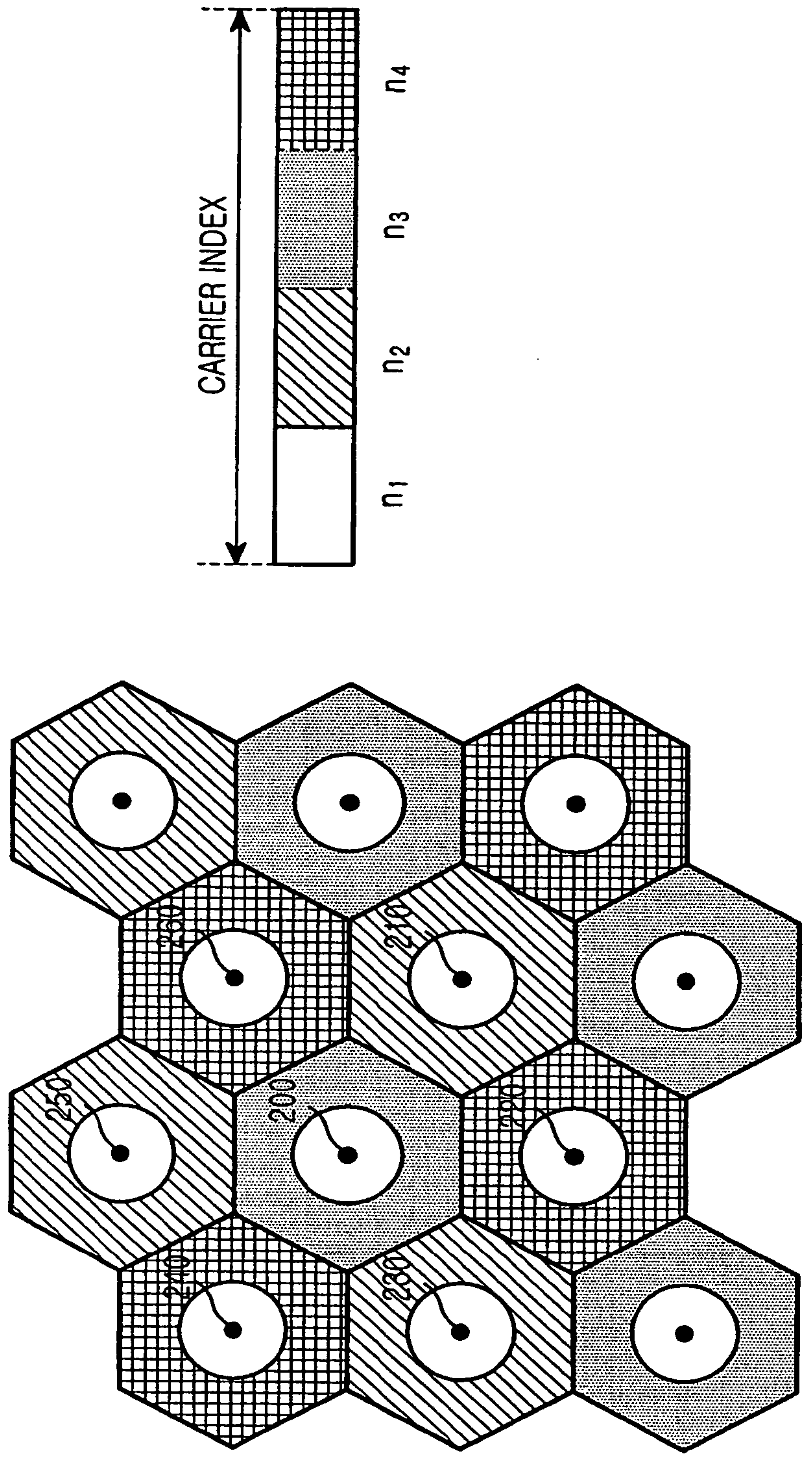


FIG.2

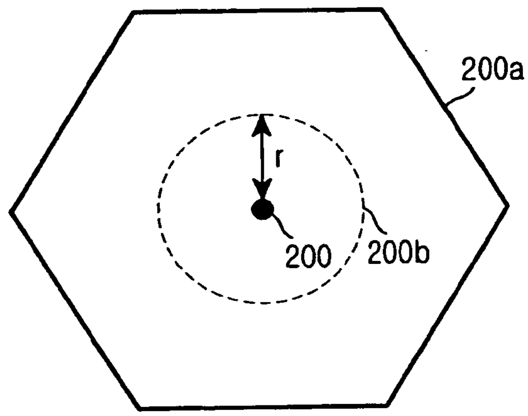


FIG.3

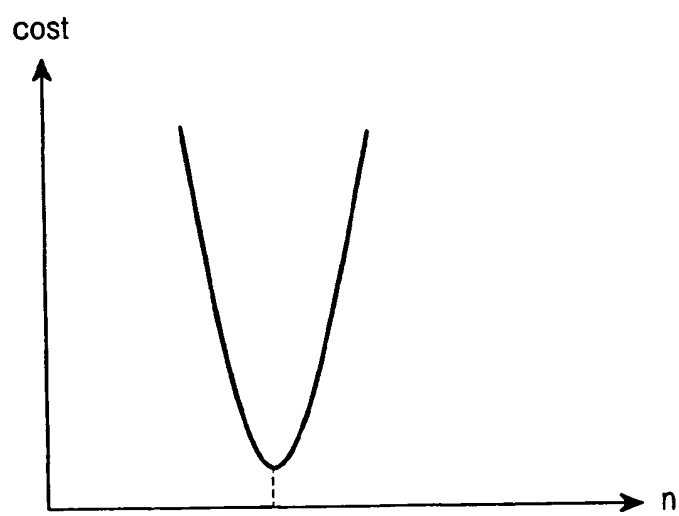


FIG.4

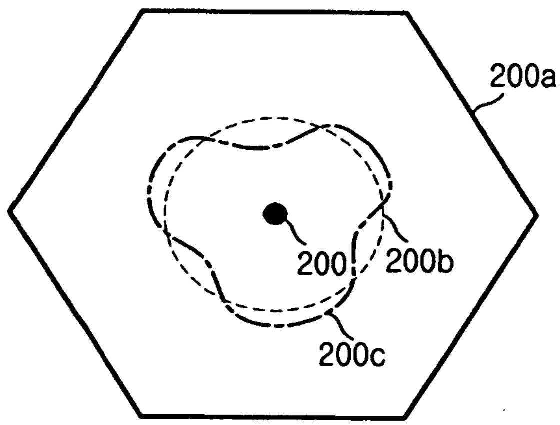


FIG.5

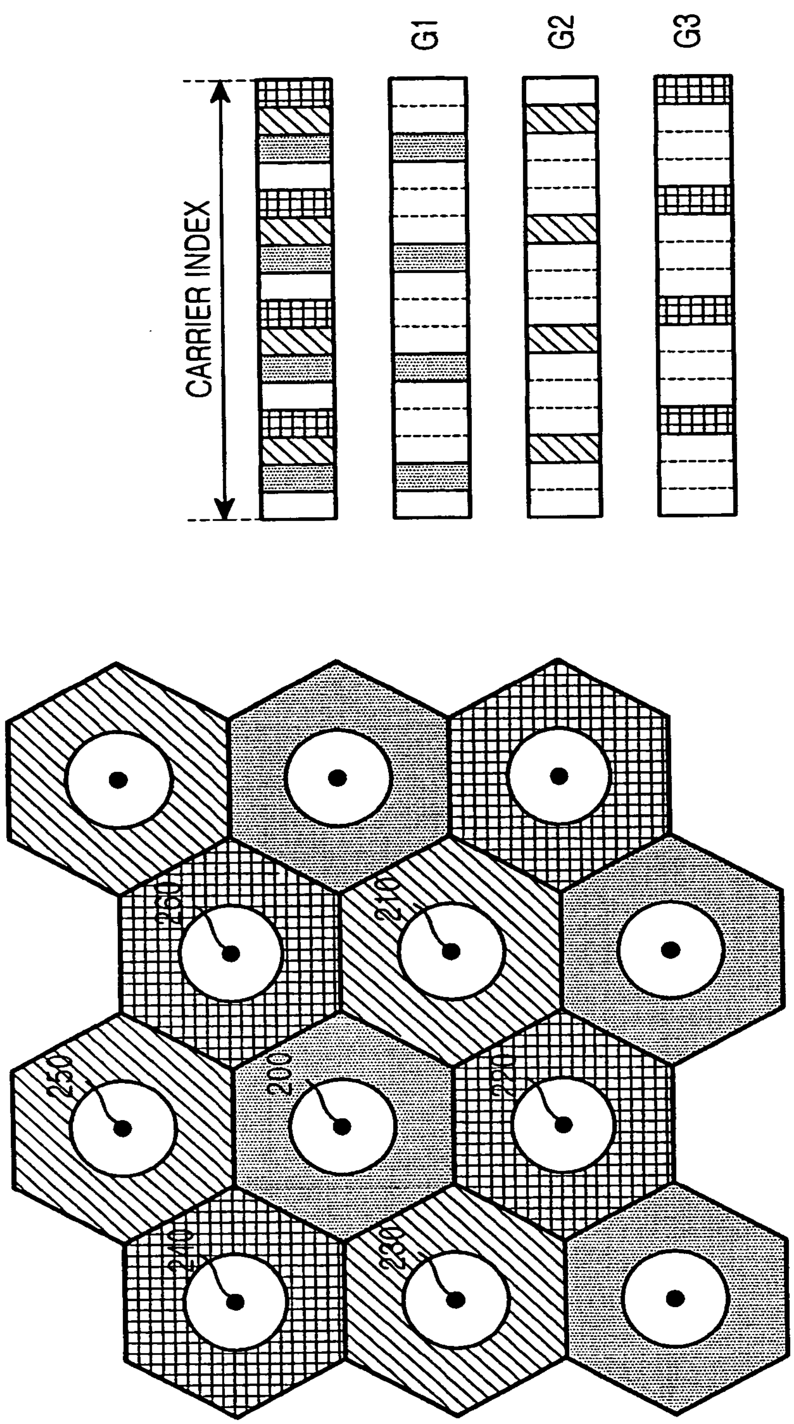


FIG.6

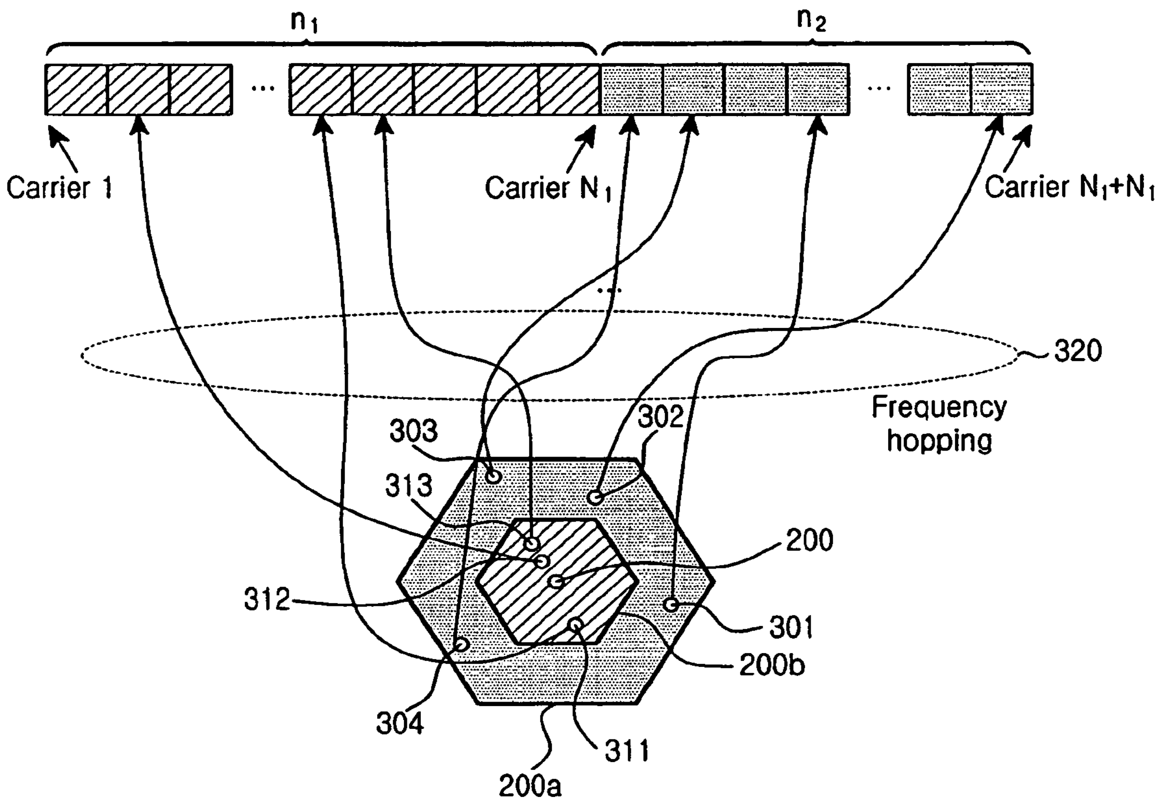

n1
n2
Carrier 1
Carrier N1
Carrier N1+N1
320
Frequency hopping
303
302
313
200
312
301
200b
304
311
200a

FIG.7

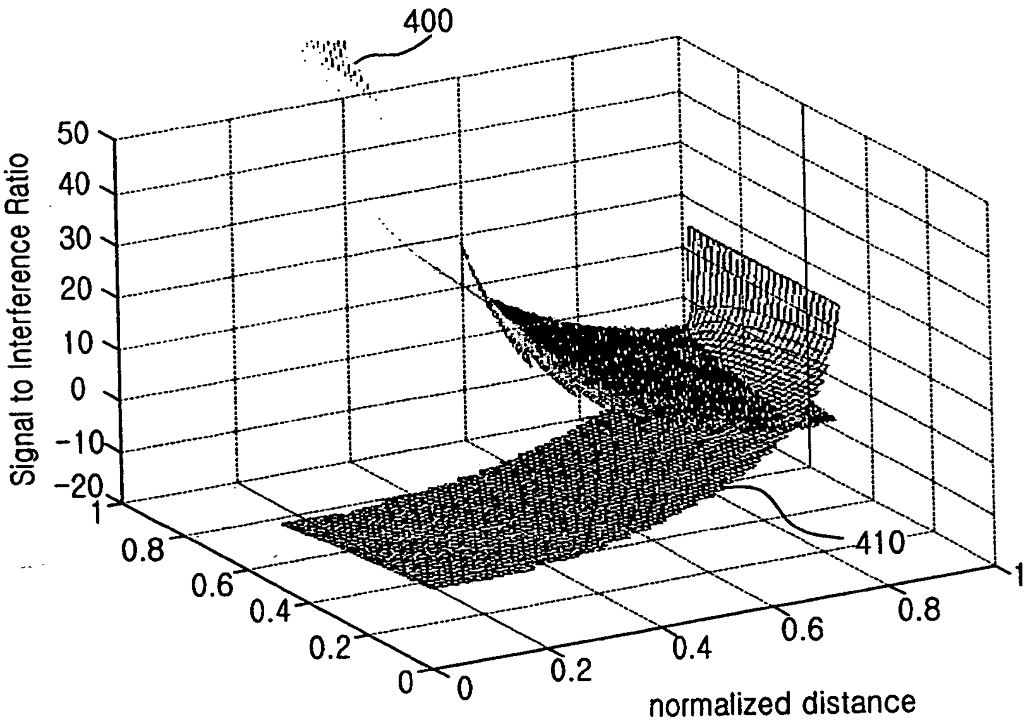

400
Signal to Interference Ratio
50
40
30
20
10
0
-10
-20
1
0.8
0.6
0.4
0.2
0
0
0.2
0.4
0.6
0.8
1
normalized distance
410

FIG.8

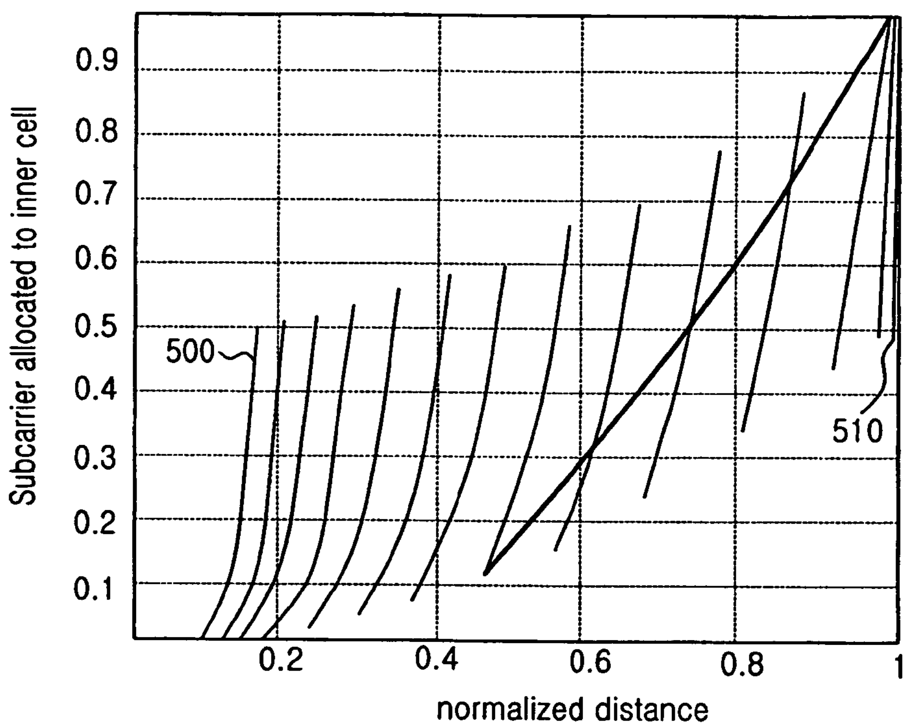

Subcarrier allocated to inner cell
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
500
510
0.2
0.4
0.6
0.8
1
normalized distance

FIG.9

European Patent Office

EUROPEAN SEARCH REPORT

Application Number
EP 03 07 8518

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.7)
X	EP 0 782 360 A (AT & T CORP) 2 July 1997 (1997-07-02) * page 2, line 20 - line 26 * * page 2, line 38 - line 42 * * page 9, line 54 - page 12, line 35; claims 1,7 * ---	1-7,11	H04Q7/36
X	WO 02 49306 A (BROADSTORM TELECOMMUNICATIONS) 20 June 2002 (2002-06-20) * paragraph [0067] - paragraph [0075]; claims 1,18,25,30 *	17	
Y	* paragraph [0082] - paragraph [0087]; claims 1,10,25,30 *	12,14	
A	* paragraph [0008] * * paragraph [0025] - paragraph [0027] * * paragraph [0082] - paragraph [0111] * * paragraph [0104] - paragraph [0105] * * claims 1,10,14 * ---	1-8,11, 13,15, 16,18,21	
Y	US 5 953 661 A (SCHWINGHAMMER PAT ET AL) 14 September 1999 (1999-09-14) * column 3, line 60 - column 5, line 11; figures 1,2 * ---	12,14	TECHNICAL FIELDS SEARCHED (Int.Cl.7) H04Q H04L
A	WANG ZHAOCHENG ET AL: "Frequency reuse scheme for cellular OFDM systems" ELECTRONICS LETTERS, IEE STEVENAGE, GB, vol. 38, no. 8, 11 April 2002 (2002-04-11), pages 387-388, XP006018189 ISSN: 0013-5194 * the whole document * -----	1-22	

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
MUNICH	5 March 2004	Grimaldo, M

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
Y : particularly relevant if combined with another document of the same category
A : technological background
O : non-written disclosure
P : intermediate document

T : theory or principle underlying the invention
E : earlier patent document, but published on, or after the filing date
D : document cited in the application
L : document cited for other reasons

& : member of the same patent family, corresponding document

EPO FORM 1503 03 82 (P04C01)

ANNEX TO THE EUROPEAN SEARCH REPORT ON EUROPEAN PATENT APPLICATION NO. EP 03 07 8518

This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report.
The members are as contained in the European Patent Office EDP file on
The European Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

05-03-2004

Patent document cited in search report		Publication date	Patent family member(s)			Publication date
EP 0782360	A	02-07-1997	US	6181918	B1	30-01-2001
			EP	0782360	A2	02-07-1997
			JP	9205678	A	05-08-1997
			SG	79929	A1	17-04-2001
WO 0249306	A	20-06-2002	US	2002119781	A1	29-08-2002
			US	2003169681	A1	11-09-2003
			AU	3258902	A	24-06-2002
			AU	3521702	A	24-06-2002
			AU	3662702	A	24-06-2002
			CA	2431502	A1	20-06-2002
			CA	2431844	A1	20-06-2002
			CA	2431849	A1	20-06-2002
			EP	1344365	A2	17-09-2003
			WO	0249305	A2	20-06-2002
			WO	0249306	A2	20-06-2002
			WO	0249385	A2	20-06-2002
			US	2002147017	A1	10-10-2002
US 5953661	A	14-09-1999	EP	0981917	A2	01-03-2000
			WO	9852364	A2	19-11-1998

EPO FORM P0459

For more details about this annex : see Official Journal of the European Patent Office, No. 12/82

THIS PAGE LEFT BLANK

03 P 12007

B7

(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
6 February 2003 (06.02.2003)

PCT

(10) International Publication Number
WO 03/010901 A1

(51) International Patent Classification[7]: H04B 7/26, H04J 13/02, H04L 5/02, 27/26

(21) International Application Number: PCT/CA02/01119

(22) International Filing Date: 17 July 2002 (17.07.2002)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
2,354,196 26 July 2001 (26.07.2001) CA

(71) Applicant *(for all designated States except US)*: **SOMA NETWORKS, INC.** [US/US]; Legal Department, China Wharf Basin, Suite 2000, 185 Berry Street, San Francisco, CA 94107 (US).

(72) Inventors; and
(75) Inventors/Applicants *(for US only)*: **LAMONTAGNE, Rene** [CA/CA]; Suite 6, 110 Clarence Street, Ottawa, Ontario K1N 5P6 (CA). **WU, Shiquan** [CA/CA]; Suite 6, 110 Clarence Street, Ottawa, Ontario K1N 5P6 (CA).

(74) Agent: STRATTON, Robert., P; SOMA Networks, Inc., 312 Adelaide Street West, Suite 700, Toronto, Ontario M5V 1R2 (CA).

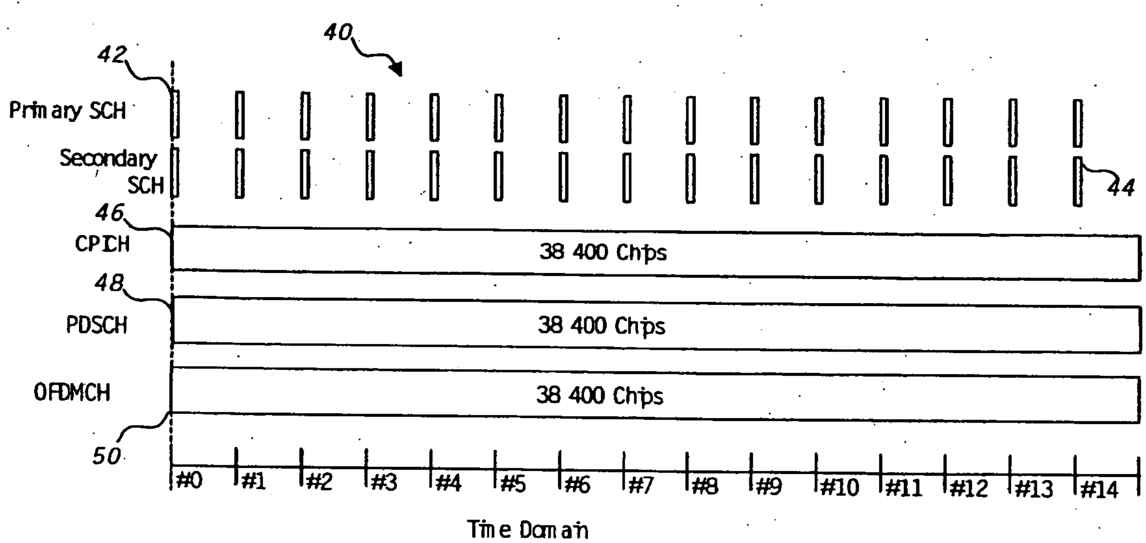
(81) Designated States *(national)*: AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NO, NZ, OM, PH, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VN, YU, ZA, ZM, ZW.

(84) Designated States *(regional)*: ARIPO patent (GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE, SK, TR), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Published:
— *with international search report*

[Continued on next page]

(54) Title: METHOD OF AND APPARATUS FOR COMMUNICATION VIA MULTIPLEXED LINKS



(57) Abstract: A communication structure and method which allows connection-like and connectionless communications to be provided on a multiplexed link is provided. The structure and method can make efficient use of available transmission capacity and/or network resources while providing both types of communication and hybrids. Connection-like communications can be provided by a dedicated code division multiplexed channels having allocated transmission capacity dedicated to the communication while connectionless communication can be provided by a shared orthogonal frequency division multiplexed channel through which data can be transmitted to subscribers. In an embodiment, the shared channel transmits inverse fast fourier transformed frequency sub-bands allocated to one or more of the subscribers. The allocation of the sub-bands can be fixed, or dynamically quantized or proportional.

WO 03/010901 A1

METHOD OF AND APPARATUS FOR COMMUNICATION VIA MULTIPLEXED LINKS

Field of the Invention

The present invention relates to a method of and apparatus for communication, and is particularly concerned with transmitting data, which can include both voice data and non-voice data, via a multiplexed link.

Background of the Invention

Many communications systems are known. Early communications systems were connection-based, in that a connection was physically established through the system between the communicating nodes. For example, in the early versions of the public switched telephone network (PSTN), users were provided a point-to-point connection to other users through switchboards, switches and trunks. More recently, the PSTN has employed multiplexed lines that are shared, through at least some part of the network, by multiple users, but which still provide a fixed amount of bandwidth and network capacity to each user for their connection, these bandwidth and network capacities being selected as meeting the anticipated maximum requirements for a common telephone voice conversation, typically referred to as toll quality.

Data communications systems have also been built which are connectionless. Connectionless systems generally operate on a best effort and/or statistical basis to deliver data via a suitable, but not necessarily fixed, route between the users, at best effort transmission rates and/or error rates. An example of a connectionless system is a packet network such as the Internet wherein the network capacity is shared amongst the users.

More recently, attempts have been made to combine connectionless and connection-like services in a single communication system. For example, much interest has been expressed recently in voice over IP (VoIP) through the Internet. However, it has proven difficult and/or costly to create a communication system which can meet both the connection-like requirements of VoIP (utilizing a moderate data rate and having some tolerance for errors, but requiring low latency) and connectionless data (often utilizing a high, bursty data rate and having a relatively high tolerance to latency but little tolerance for errors).

Attempts have been made to provide a connection-like mechanism via the Internet. One such attempt is the ReSerVation (RSVP) Protocol proposed by some vendors and which allows network capacity to be "reserved" at routers and switches to establish a "virtual" connection through the Internet to better ensure that desired quality of service (QoS) levels will be met for

the virtual connection. However, support for RSVP must explicitly be implemented within an application and at each switch and/or router involved in the virtual connection, which has been difficult to achieve to date. Further, there is a significant amount of time and overhead required to set up an RSVP connection which can negate the benefits of an RSVP connection for connections of relatively short duration. Even when implemented, RSVP does not typically result in an efficient usage of network capacity as the maximum anticipated bandwidth and/or network capacity requirements must be reserved for the duration of the connection, even if they are not used, or are not used continuously. Thus, in many circumstances, reserved network resources are sitting idle, or are under utilized, for some portion of time. Further, RSVP does not include any incentive mechanism by which applications/users are encouraged to only make effective use of network resources, i.e. – unreasonable requests for resources can be made by a user or application as there are no economic or other disincentives for doing so.

Such difficulties are exacerbated when the links on which the network, or a portion of the network, is implemented involve a multiplexed link of expensive and/ or limited bandwidth. In such cases efficient utilization of bandwidth and/or network resources is very important and RSVP or similar strategies have difficulty in meeting desired efficiencies. As used herein, the term multiplex and/or multiplexed link are intended to comprise any system or method by which a link is shared amongst users. Examples of such multiplexed links include wired or wireless links employing multiplexing systems such as TDMA, CDMA, FDMA or other arrangements.

A specific prior art example of a communication system providing digital voice transmission over a multiplexed wireless link is a PCS (Personal Communication System) cellular system. Such systems can employ a multiplexing technique such as CDMA, TDMA, hybrid systems such as GSM, or other strategies to allow multiple callers to share the wireless link between the cellular base station and the PCS mobile units in both the upstream (mobile to base station) and downstream (base station to mobile) directions. One popular such system is the CDMA-based IS-95 cellular system in use in North America, South Korea and Japan.

More recently, so-called third generation wireless proposals have been developed by groups interested in providing higher data rates for wireless communications. One such group is the 3rd Generation Partnership Project (3GPP). The 3GPP have been working to extend the work done on the Global System for Mobile communication (GSM) to extend the radio access technologies, Universal Terrestrial Radio Access (UTRA) for both frequency division duplex (FDD) and time division duplex (TDD) modes. The FDD and TDD modes are to be used on a

cell basis, that is a given cell is either operating in an FDD mode or a TDD mode.

It is therefore desired to have a communications apparatus and method of providing data communications, including voice data, over wireless or other multiplexed links.

Summary of the Invention

It is an object of the present invention to provide a method of and apparatus for communication via a multiplexed link.

According to an aspect of the present invention, there is provided a communications structure for communicating between at least one network node and at least two subscriber stations through a multiplexed link, said structure comprising a plurality of code division multiple access (CDMA) channels, each channel having allocated to it a portion of the transmission power budget of said link to provide communication between said network node and one of said at least two subscriber stations and a shared orthogonal frequency division multiplex (OFDM) channel having allocated to it a portion of the transmission power budget of said link, said shared channel providing a plurality of sub-bands for transmission of data from said network node to said at least two subscriber stations, whereby the shared OFDM channel, providing a relatively high data rate, overlaps the CDMA channels to maintain compatibility therewith.

According to another aspect of the present invention, there is provided a method of communicating between at least one network node and at least two subscriber stations through a multiplexed link, said method comprising the steps of while maintaining a dedicated code division multiplexed communications channel to each of said at least two subscriber stations, monitoring demand for transmission of data from said network node to any of said at least two subscriber stations and responsive to determining such demand, allocating at least one sub-band of a shared orthogonal frequency division multiplexed channel providing a plurality of sub-bands for transmission of data from said network node to said at least two subscriber stations to one subscriber station.

According to yet another aspect of the present invention, there is provided a communications network comprising at least two subscriber stations, and a base station having means for maintaining a dedicated code division multiplexed communications channel to each of said at least two subscriber stations, means for monitoring demand for transmission of data from said network node to any of said at least two subscriber stations; and means, responsive to determining such demand, allocating at least one sub-band of a shared orthogonal frequency

division multiplexed channel providing a plurality of sub-bands for transmission of data from said network node to said at least two subscriber stations to one subscriber station.

According to a further aspect of the present invention, there is provided a method of communicating between at least one network node and at least two subscriber stations through a multiplexed link, said method comprising the steps of monitoring service requests from the at least two subscriber stations and responsive to a request providing one of a dedicated code division multiplexed communications channel to each of said at least two subscriber stations, a shared orthogonal frequency division multiplexed channel and while maintaining a dedicated code division multiplexed communications channel to each of said at least two subscriber stations, monitoring demand for transmission of data from said network node to any of said at least two subscriber stations, and responsive to determining such demand, allocating at least one sub-band of a shared orthogonal frequency division multiplexed channel providing a plurality of sub-bands for transmission of data from said network node to said at least two subscriber stations to one subscriber station.

The present invention provides a communication apparatus for and method of connection-like and connectionless communications on a multiplexed communication link. The apparatus and method can make efficient use of available bandwidth and/or network resources while providing both types of communication. Connection-like communications can be provided by a shared channel having allocated power dedicated to the communication while connectionless communication can be provided by allocating portions of a frequency band that is allocated a portion of the power budget for the communications link. In an embodiment, the frequency band is divided into sub-bands also known as bins and the bins are allocated on a demand basis. Orthogonal Frequency Division Multiplexing (OFDM) is used to transmit data to the users who have been allocated one or more sub-bands.

Brief Description of the Drawings

Preferred embodiments of the present invention will now be described, by way of example only, with reference to the attached Figures, wherein:

Fig. 1 illustrates a wireless local loop system employing a multiplexed radio link;

Fig. 2 illustrates a known communications system channel structure;

Fig. 3 illustrates downlink physical channels in accordance with an embodiment of the present invention;

Fig. 4 illustrates an OFDM symbol in the frequency domain for the OFDM channel of

Fig. 3;

Fig. 5 illustrates an OFDM symbol in the time domain for the OFDM channel of Fig. 3;

Fig. 6 illustrates an OFDM system architecture with space-time transmit diversity (STTD) in accordance with an embodiment of the present invention;

Fig. 7 illustrates an training symbol in the frequency domain for both channel A and B of Fig. 6;

Fig. 8 illustrates apparatus for transmitting data multiplexed according to the method of Figs. 6 and 7 together with other data in accordance with an embodiment of the present invention; and

Fig. 9 illustrates apparatus for receiving the data multiplexed according to the method of Figs.6 and 7.

Detailed Description of the Invention

Referring to Fig. 1, there is illustrated a wireless local loop (WLL) system, indicated generally at 10. System 10 includes at least one network node, such as base station 12, which is connected to one or more networks, such as the PSTN and/or the Internet, and/or to one or more other base stations 12, via a back haul 14. Each base station 12 communicates with a plurality of subscriber stations 16 via a multiplexed radio link 18 shared between subscriber stations 16a-n. In Figure 1, each subscriber station 16 can provide simultaneous connections to at least one telephony device 20, such as a telephone set or facsimile machine, and a data device 22 such as a computer or video conferencing system.

Radio link 18 employs a suitable multiplexing technique, such as TDMA, FDMA, CDMA, hybrids thereof or other multiplexing techniques to allow simultaneous use of radio link 18 by more than one subscriber station 16 and/or base station 12.

In prior art systems where, for example, subscriber stations are mobile telephones, a base station can assign the usage of a portion of a radio link to a subscriber station, on an as-needed basis. For example, in a system employing IS-95, the radio link is divided into a sixty-four channels in the forward link from the base station to the subscriber station. Some of these channels are dedicated for control and signaling purposes between the base station and subscriber stations, and the balance form a pool of traffic channels, one or more of which can be assigned as needed, to communicate with a subscriber station.

The IS-95 communication system suffers from certain disadvantages. For example, the channels are of fixed pre-selected data rate (e.g., 9.6 or 14.4 kilobits per second) and use of a

traffic channel is reserved for the duration of the connection, even if the connection is not currently using the link resources (bandwidth and/or code space) allocated to the channel. It is not unusual that a voice conversation includes relatively long pauses wherein no information is transmitted and channel bandwidth is essentially wasted (although in CDMA, this results in a desirable reduction in interference between users).

When connectionless services are considered, this problem is much worse as transmissions to a data device, such as a computer, can comprise one or only a few packets that typically arrive in bursts, rather than at a steady rate. A channel established for such a connectionless service will therefore typically not use a large part of its allocated link resources, yet these unused resources are reserved for the duration of that connection and are unavailable for use elsewhere in the system until the channel is freed. In addition, there is a relatively significant overhead required to assign a channel between a base station and a subscriber station. Thus, for connectionless services between a base station and a subscriber station, the time and/or network processing requirements for establishing a channel can be unreasonable for short bursts of packets.

Referring to Fig. 2, there is illustrated a known downstream (from base station to users) channel structure for 3GPP UTRAN, FDD mode. The downlink channels 30 are shown for a 10 ms period. The downlink channels 30 include primary and secondary synchronization channels (SCH) 32 and 34, a common pilot channel (CPICH) 36, and a physical downlink shared channel (PDSCH) 38. A complete specification of the physical channels for 3GPP™ FDD is provided in 3GPP TS 25.211 V4.0.0 (2001-03) Technical Specification Group Radio Access Network; Physical channels and mapping of transport channels onto physical channels (FDD) (Release 4). This specification and other technical specifications for 3GPP™ can be downloaded from the website: www.3gpp.org.

The proposed 3GPP Universal Terrestrial Radio Access (UTRA) in frequency division duplex mode (FDD) provides for various rates of data transmission. In order to transmit at the higher data rates, the spreading factor must be reduced. Unfortunately, a lower spreading factor means that the inter-symbol interference portion of the received signal, in a multi-path environment does not cancel out, as is the case with a higher spreading factor. Consequently, the use of a low spreading factor effectively defeats one of the main benefits normally associated with using CDMA. Hence, at higher data rates intersymbol interference (ISI) becomes problematic.

Referring to Fig. 3 there are illustrated downlink physical channels in accordance with an embodiment of the present invention. The downlink channels 40 are shown for a 10 ms period. The downlink channels 40 include primary and secondary synchronization channels (SCH) 42 and 44, a common pilot channel (CPICH) 46, a physical downlink shared channel (PDSCH) 48, and an orthogonal frequency division multiplex channel (OFDMCH) 50.

The downlink channels 40 are shown for a 10ms period, as with the 3GPP UTRAN, FDD mode of Fig. 2, the downlink channels 40 include primary and secondary synchronization channels (SCH) 42 and 44, the common pilot channel 46, and physical downlink shared channel (PDSCH) 48. In addition, orthogonal frequency division multiplex channel (OFDMCH) 50 is added. The OFDMCH 50 uses orthogonal frequency division multiplexing (OFDM). From a total broadcast power budget, power is allocated in dependence upon relative traffic from data versus other channels, between the OFDMCH 50 and the PDSCH 48.

In operation of the wireless network of Fig. 1, in accordance with an embodiment of the present invention the OFDMCH 50 is combined with the other downlink channels as described in detail herein below. In order to overlay the OFDMCH 50 on the PDSCH 48, a low spreading factor is used, typically of 64 or less. To the PDSCH 48, the OFDMCH50 looks like noise, and can be received provided sufficient signal-to-noise is available.

While the present embodiment has been described in terms providing the OFDMCH50, a practical system based on the present embodiment would include the ability to respond to subscriber requests either by providing the OFDMCH 50 only, the OFDMCH 50 overlaid on the PDSCH 48 or the PDSCH 48. The combined OFDMCH 50 and PDSCH 48 provide both the capability of providing high-speed data while maintaining compatibility with 3GPP FDD for voice and low-speed data, while avoiding the ISI problems associated with a high data rate using just the PDSCH 48.

Referring to Fig. 4 there are illustrated OFDM symbols in the frequency domain for the OFDM channel of Fig. 3. The OFDMCH symbols are converted into chips by inverse fast Fourier transform (IFFT), there being 36 1K-OFDM symbols within each 10 ms timeframe. The OFDMCH 50 has a configurable number of slots from 1 to 35 for each user assignment (with 36 being occupied by pilot) and is time multiplexed with other channels for transmission. One OFDM channel frame 50 includes chips designated for Tx1 and Tx2 pilots 52 and 54, transmitter parameter signaling (TPS) 56, data 58 and reserved 60. Different users can be separated either by different subcarrier groups and time slots, or by Wash code cover in

frequency domain. Each OFDM symbol has 1024 sub-carriers with a sub-carrier separation 3.84 MHz/1024=3.75kHz. Table A provides a legend for Fig. 4:

Table A

Reference Char	Symbol	Represents
52	①	Tx1 Pilot
54	②	Tx2 Pilot
56	Ⓣ	TPS
58	Ⓓ	Data
60	Ⓡ	Reserved

Referring to Fig. 5 there is illustrated an OFDM symbol in the time domain for the OFDM channel of Fig. 3. Each bin of 1024 chips of data as represented by a block 62 is multiplied by a clocked primary pseudo-random code 64 at 66 and applied as input to an inverse fast Fourier transform (IFFT) engine 68 to provide either a pilot OFDM symbol 70 (if pilot data provided) or a normal data OFDM symbol 80. The pilot OFDM symbol 70 includes a preamble 72 of 66 samples copied from the last 66 samples 74 of the 1024 data samples with the first 958 samples 76 there between. The normal OFDM symbol 80 includes a preamble 82 of 42 samples copied from the last 42 samples 84 of the 1024 data samples with the first 982 samples 86 there between. The preamble is chosen to account for delay spread within the system 10. Each normal OFDM symbol has 42 chips prefix to cover 11ms delay spread and each pilot OFDM symbol has 66 chips prefix.

In operation, connectionless data to be sent to a subscriber station 16 is sent on the OFDMCH 50. The bins or slots are allocated in dependence upon demand to send such data to the subscriber stations 16a-n. Hence, one subscriber, for example the subscriber station 16a may, during a 10 ms time period, have no data waiting to be sent and is therefore not allocated any bins. While a second subscriber, e.g., the subscriber station 16b may have twice as much data as a third subscriber, e.g. the subscriber station 16n. In this example, if these were the only two subscribers that were to receive connectionless data, two-thirds of the slots would be allocated to the subscriber station 16b while the remaining one-third was allocated to the subscriber station 16n. In this manner, the bandwidth of the broadcast data channel is allocated on the basis of need. Dynamic allocation of the bins could, for example be based upon simple metrics such as buffer occupancy. This is a very simple example of how the bins could be

allocated, clearly one of ordinary skill in the art would know or could devise more complex algorithms for allocating the bins between subscribers.

Once the bins are allocated, for a given 10 ms time period, the data is converted from the frequency domain to the time domain by the IFFT engine 68. The orthogonal frequency domain multiplexing OFDM allows the chips being transmitted to be closely spaced, yet recoverable at the subscriber station 16 without the use of complex channel equalization. This is due to the shape of the spectrum for each sample in the time domain.

Referring to Fig. 6 there is illustrated a method of multiplexing data in accordance with an embodiment of the present invention. The method 100 includes coding and modulating 102, and orthogonal frequency division modulating 104.

Coding and modulating 102 includes the steps of CRC adding 112, forward error correction (FEC) 114, rate matching 116, bit interleaving 118, variable modulator mapping 120, and symbol interleaving 122.

Orthogonal frequency division modulating 104 includes 1:M demultiplexing 124, transmitter parameter signaling inserting 126, inverse fast Fourier transforming 128, 1:M multiplexing 130, prefix inserting 132, hard limiting 134, and outputting a time domain signal 136.

Between the coding/modulating 102 and the orthogonal frequency division modulating 104 there are additional steps of STTD/STC encoding 106, Wash covering 108 and scrambling 110.

TPS (transmitter parameter signaling) is reserved for upper layer signaling purposes. Each subscriber station 16 decodes these TPS first to know which sub-carriers/slots belong to it. Each of the two branches outputs a time domain complex data vector of dimension 35x(1024+42) = 37310 that will go to a channel combination block.

Referring to Fig. 7 there is illustrated an OFDM training symbol in the frequency domain for the OFDM channel of Fig. 3. The OFDM training symbol is the first of 36 OFDM symbols of each 10 ms frame. In Fig. 6, the first OFDM symbol of each 10 ms frame is not included. This OFDM symbol is a known training symbol and is used for system acquisition channels estimation purposes. Mobility can be handled by inserting more training symbols. This OFDM symbol is converted into 1024+66 = 1090 chips (Refer to Fig.5) and there is no wash cover for these known sequences, but they are scrambled according to the predetermined scrambling sequence. The OFDM training symbol includes a known symbol for TxA 138a, a known

symbol for TxB 138b and a null element 139.

Referring to Fig. 8 there is illustrated channel combination block for transmitting data multiplexed according to the method of Figs. 6 and 7 together with other data in accordance with an embodiment of the present invention. The channel combination block accepts as input, outputs 136a and 136b from the OFDM method of multiplexing 100, appends the training symbols as represented by blocks 140a for training symbol A and 140b for training symbol B and from other channels 142 and combines them at 144a and 144b, passes them through standard root raised cosine (RRC) filters 146a and 146b, respectively to antennae 148a and 148b for transmission.

Referring to Fig. 9 there is illustrated apparatus for receiving the data multiplexed according to the method of Figs. 6 and 7. The receiver 150 includes an analog to digital converter 152, a system acquisition block 154, a symbol/pilot differentiator 156, a prefix removal block 158, a fast Fourier transform block 160, a de-scrambler 162, a de-wash block 164, a channel estimator 166, a STTD decoder 168, a symbol de-interleaver 170, an LLR Calculator 172 a bit de-interleaver 174, a forward error correction decoder 176 and an output 178. Figs. 7 and 9 illustrate only the transmission and reception of the OFDM channel. The processing of other channels such as Primary SCH, Secondary SC, CPICH, and PDSCH are as provided by the evolving 3GPP standard. In the receiver 150, OFDM-BDCH decoding reverses the process in the transmitter. An accurate channel estimation is achieved by using the predetermined known sequence of Figs. 7 and 8.

The above-described embodiments of the invention are intended to be examples of the present invention and alterations and modifications may be effected thereto, by those of skill in the art, without departing from the scope of the invention, which is defined solely by the claims appended hereto.

We claim:

1. A communications structure for communicating between at least one network node and at least two subscriber stations through a multiplexed link, said structure comprising:

a plurality of code division multiple access (CDMA) channels, each channel having allocated to it a portion of the transmission power budget of said link to provide communication between said network node and one of said at least two subscriber stations; and

a shared orthogonal frequency division multiplex (OFDM) channel having allocated to it a portion of the transmission power budget of said link, said shared channel providing a plurality of sub-bands for transmission of data from said network node to said at least two subscriber stations;

whereby the shared OFDM channel, providing a relatively high data rate, overlaps the CDMA channels to maintain compatibility therewith.

2. A structure as claimed in claim 1 wherein one sub-band of said plurality of sub-bands is allocated for data communication to one of said at least two subscriber stations.

3. A structure as claimed in claim 2 wherein said one sub-band is allocated in dependence upon demand for data communication to one of said at least two subscriber stations.

4. A structure as claimed in claim 3 wherein demand is assessed during a predetermined time interval.

5. A structure as claimed in claim 4 wherein the time interval is 10 ms.

6. A structure as claimed in claim 1 wherein said shared orthogonal frequency division multiplexed channel includes said plurality of sub-bands and each sub-band includes a plurality of chips.

7. A structure as claimed in claim 6 wherein said plurality of sub-bands includes 36 sub-bands.

8. A structure as claimed in claim 7 wherein said plurality of chips includes 1024 chips.

9. A method of communicating between at least one network node and at least two subscriber stations through a multiplexed link, said method comprising the steps of:

while maintaining a dedicated code division multiplexed communications channel to each of said at least two subscriber stations, monitoring demand for transmission of data from said network node to any of said at least two subscriber stations; and

responsive to determining such demand, allocating at least one sub-band of a shared orthogonal frequency division multiplexed channel providing a plurality of sub-bands for

transmission of data from said network node to said at least two subscriber stations to one subscriber station.

10. A method as claimed in claim 9 wherein the step of monitoring include the step of determining data bit queue length for each subscriber terminal.

11. A method as claimed in claim 9 wherein the step of allocating includes allocating sub-bands in proportion to the demand.

12. A method as claimed in claim 11 wherein the step of allocating includes the steps of distributing a subset of sub-bands to each subscriber station and allocating remaining sub-bands in proportion to the demand.

13. A communications network comprising:

at least two subscriber stations; and

a base station having means for maintaining a dedicated code division multiplexed communications channel to each of said at least two subscriber stations, means for monitoring demand for transmission of data from said network node to any of said at least two subscriber stations; and means, responsive to determining such demand, allocating at least one sub-band of a shared orthogonal frequency division multiplexed channel providing a plurality of sub-bands for transmission of data from said network node to said at least two subscriber stations to one subscriber station.

14. A network as claimed in claim 13 wherein the means for monitoring includes a request queue.

15. A network as claimed in claim 14 wherein the means for allocating includes logic to determine how to service the request queue.

16. A method of communicating between at least one network node and at least two subscriber stations through a multiplexed link, said method comprising the steps of:

monitoring service requests from the at least two subscriber stations; and

responsive to a request providing one of:

(a) a dedicated code division multiplexed communications channel to each of said at least two subscriber stations;

(b) a shared orthogonal frequency division multiplexed channel; and

(c) while maintaining a dedicated code division multiplexed communications channel to each of said at least two subscriber stations, monitoring demand for transmission of data from said network node to any of said at least two subscriber stations; and responsive to

determining such demand, allocating at least one sub-band of a shared orthogonal frequency division multiplexed channel providing a plurality of sub-bands for transmission of data from said network node to said at least two subscriber stations to one subscriber station.

17. A method as claimed in claim 16 wherein the step of monitoring include the step of determining data bit queue length for each subscriber terminal.

18. A method as claimed in claim 16 wherein the step of allocating includes allocating sub-bands in proportion to the demand.

19. A method as claimed in claim 18 wherein the step of allocating includes the steps of distributing a subset of sub-bands to each subscriber station and allocating remaining sub-bands in proportion to the demand.

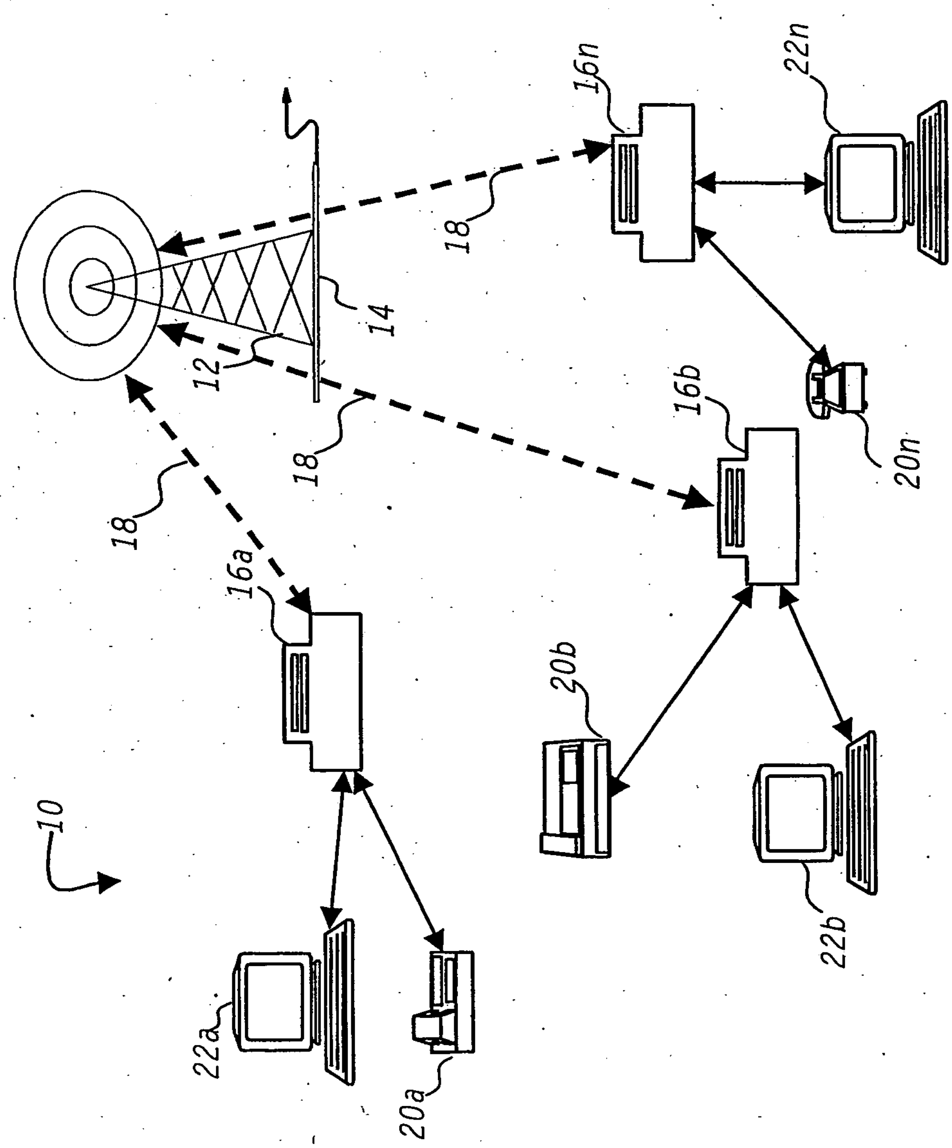


Fig. 1

3/8

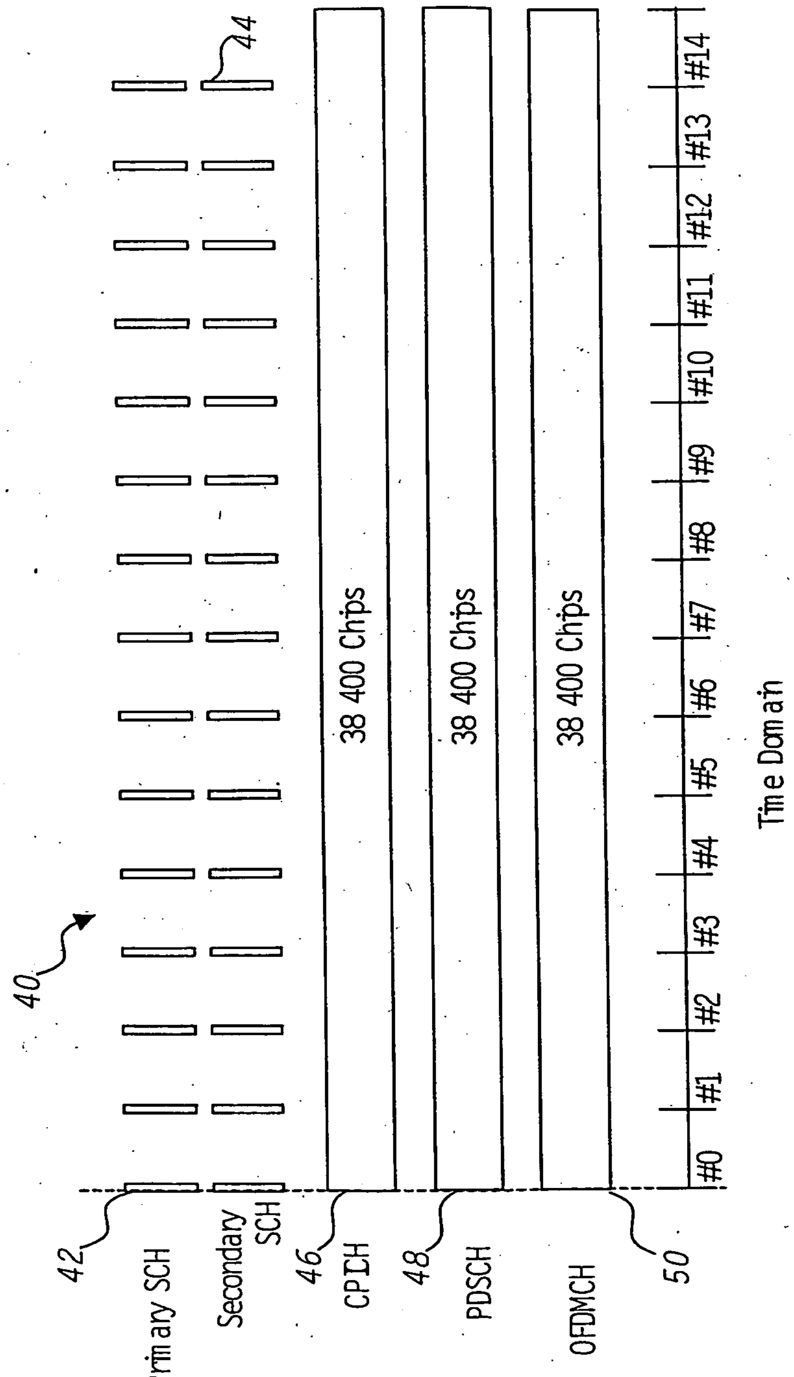

40
42
44
46
48
50
Primary SCH
Secondary SCH
CPICH
PDSCH
OFDMCH
38 400 Chips
38 400 Chips
38 400 Chips
#0
#1
#2
#3
#4
#5
#6
#7
#8
#9
#10
#11
#12
#13
#14
Time Domain

Fig. 3

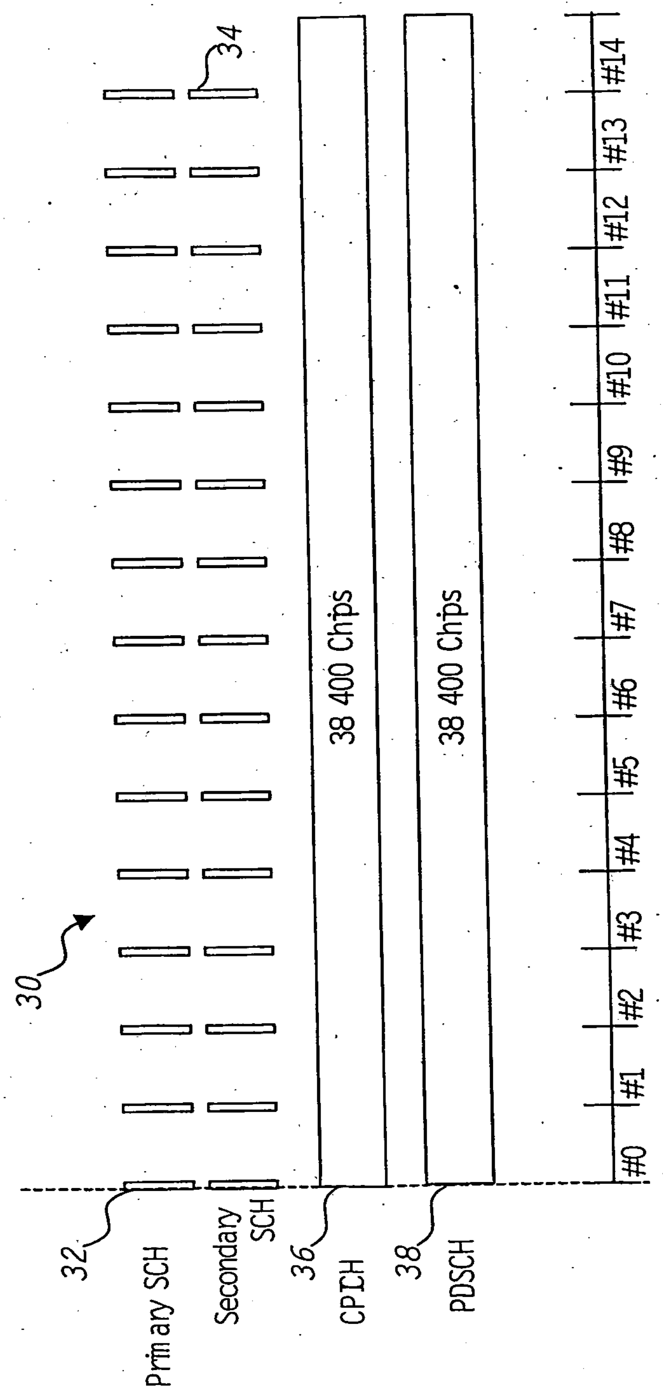


Fig. 2
(Prior art)

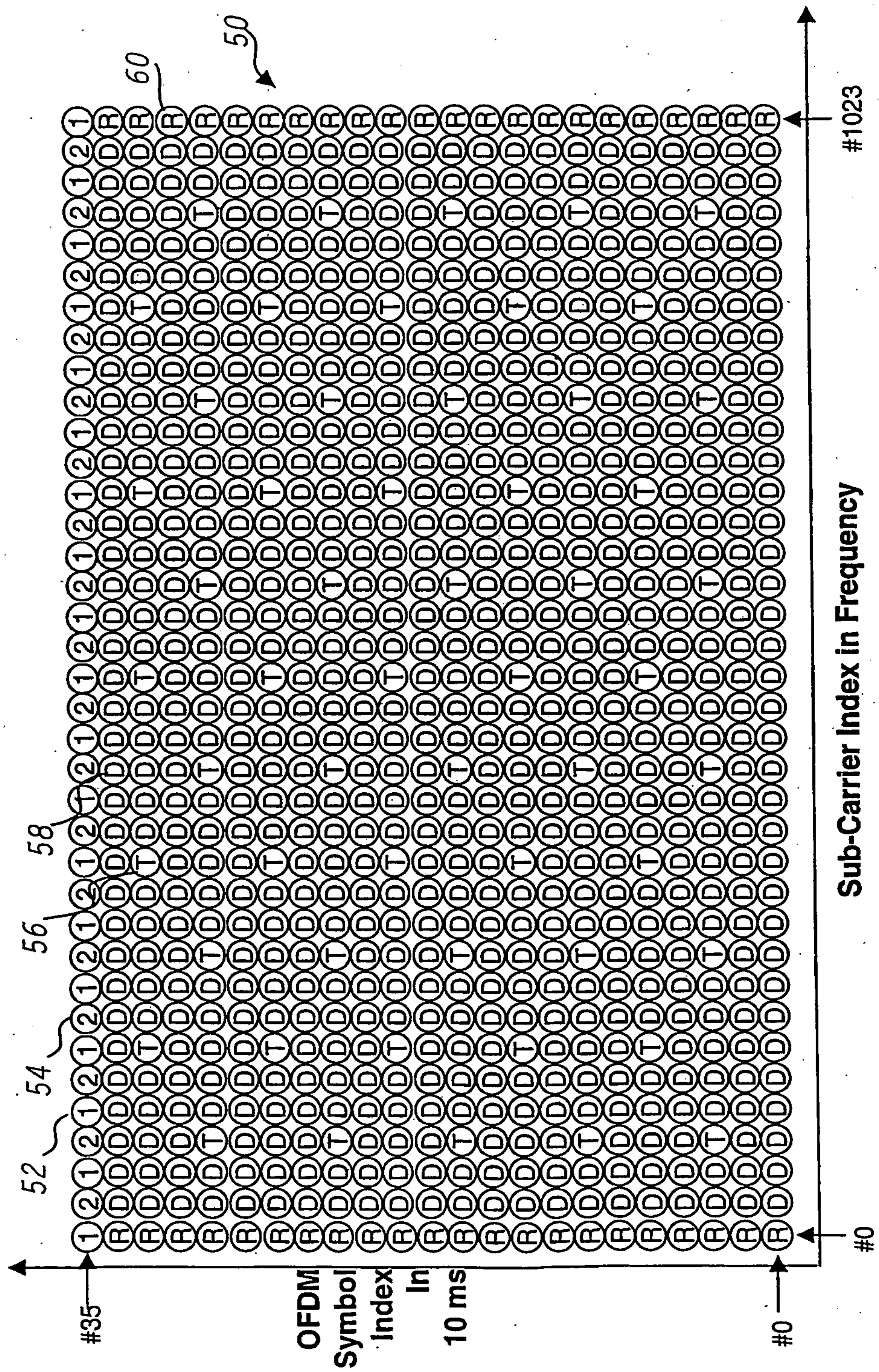

50
60
52
54
56
58
#1023
#0
#35
#0
OFDM Symbol Index In 10 ms
Sub-Carrier Index in Frequency

Fig. 4

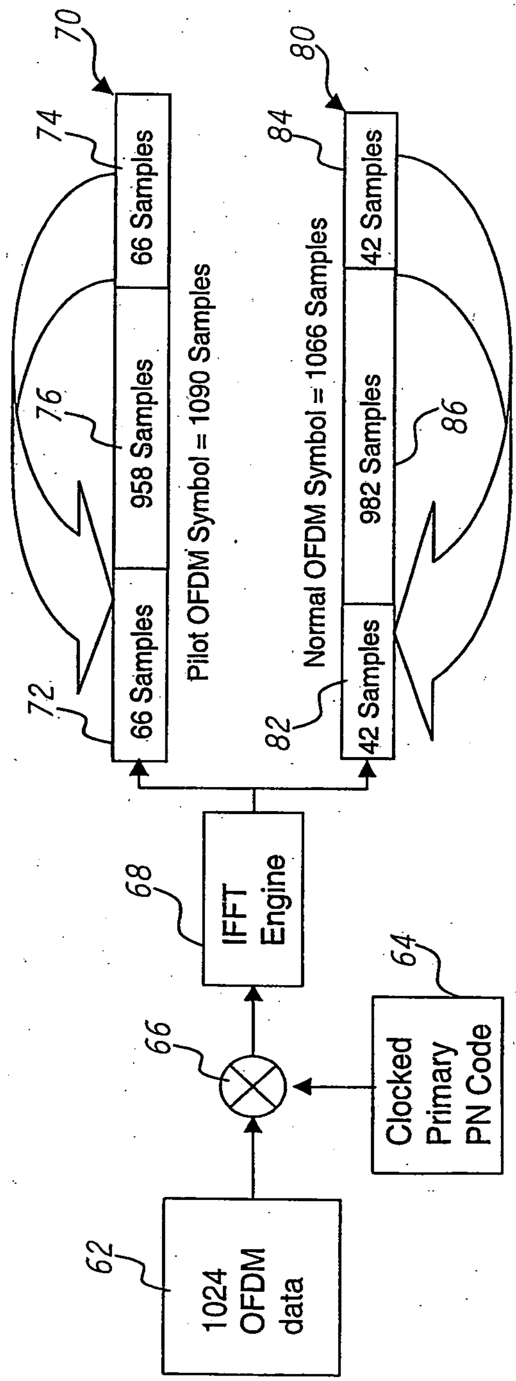

1024
OFDM
data
62
66
Clocked
Primary
PN Code
64
IFFT
Engine
68
70
74
66 Samples
958 Samples
76
66 Samples
72
Pilot OFDM Symbol = 1090 Samples
80
84
42 Samples
982 Samples
86
42 Samples
82
Normal OFDM Symbol = 1066 Samples

Fig. 5

6/8

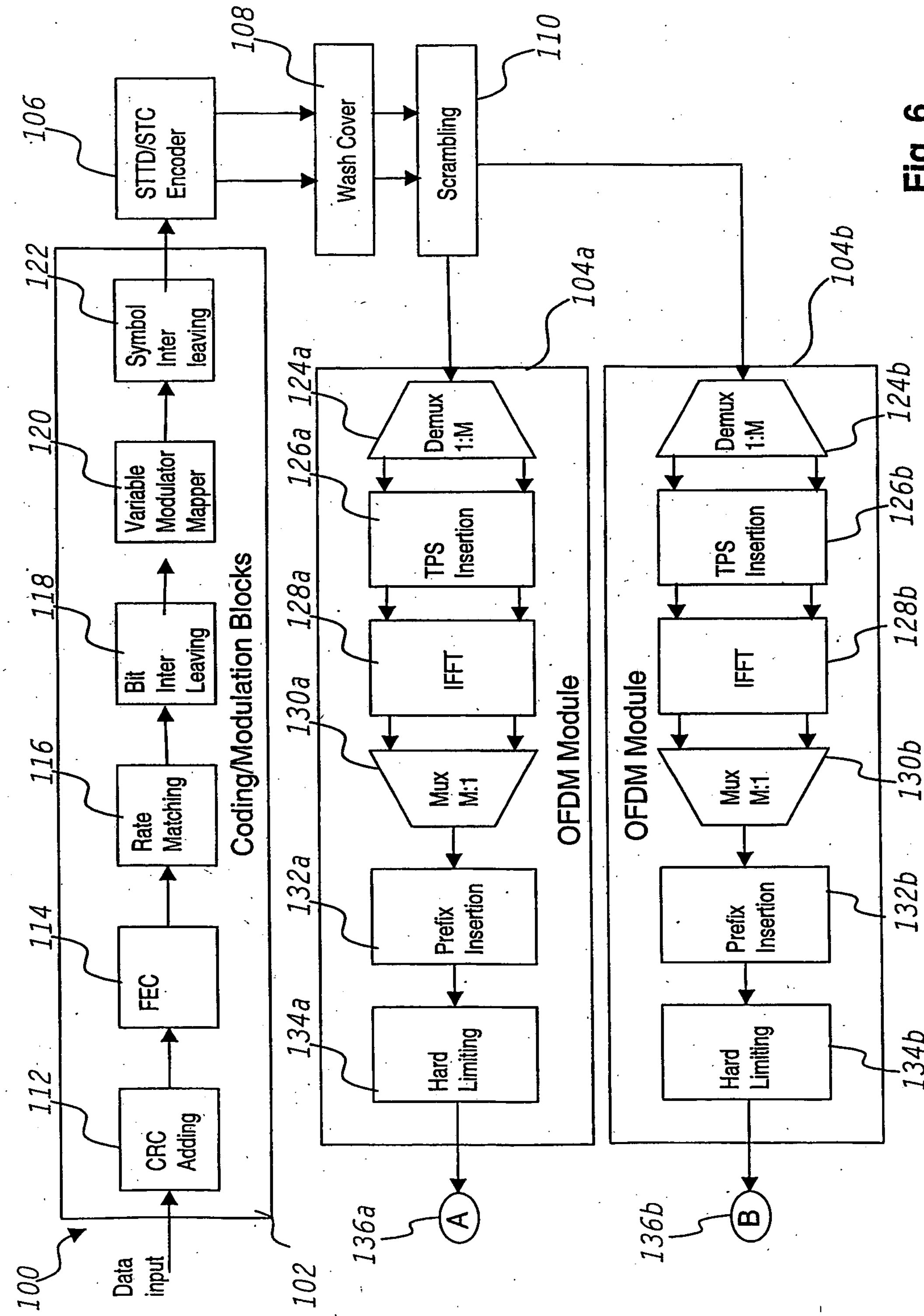

Data input
100
102
Coding/Modulation Blocks
CRC Adding
112
FEC
114
Rate Matching
116
Bit Inter Leaving
118
Variable Modulator Mapper
120
Symbol Inter leaving
122
STTD/STC Encoder
106
Wash Cover
108
Scrambling
110
OFDM Module
104a
Demux 1:M
124a
TPS Insertion
126a
IFFT
128a
Mux M:1
130a
Prefix Insertion
132a
Hard Limiting
134a
A
136a
OFDM Module
104b
Demux 1:M
124b
TPS Insertion
126b
IFFT
128b
Mux M:1
130b
Prefix Insertion
132b
Hard Limiting
134b
B
136b

Fig. 6

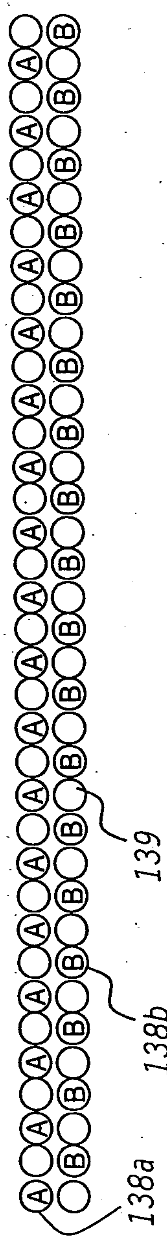

A
B
138a
138b
139

Fig. 7

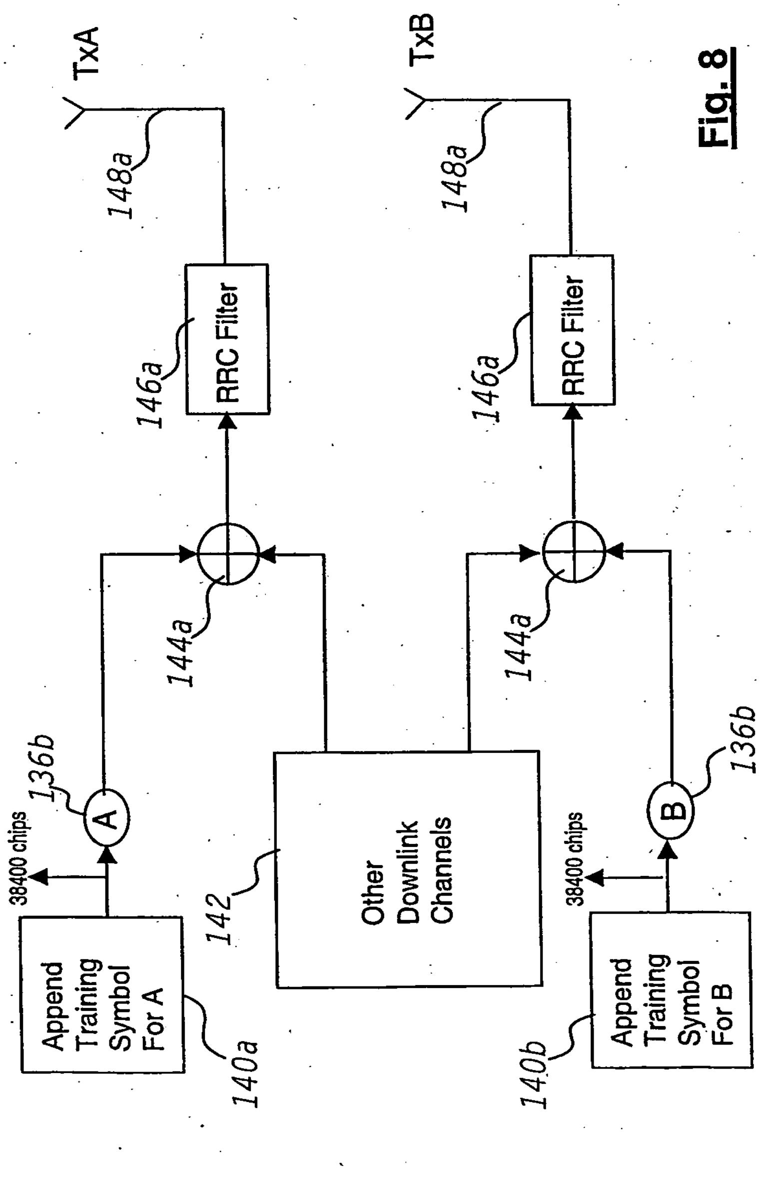

TxA
148a
RRC Filter
146a
144a
A
136b
38400 chips
Append Training Symbol For A
140a
Other Downlink Channels
142
TxB
148a
RRC Filter
146a
144a
B
136b
38400 chips
Append Training Symbol For B
140b

Fig. 8

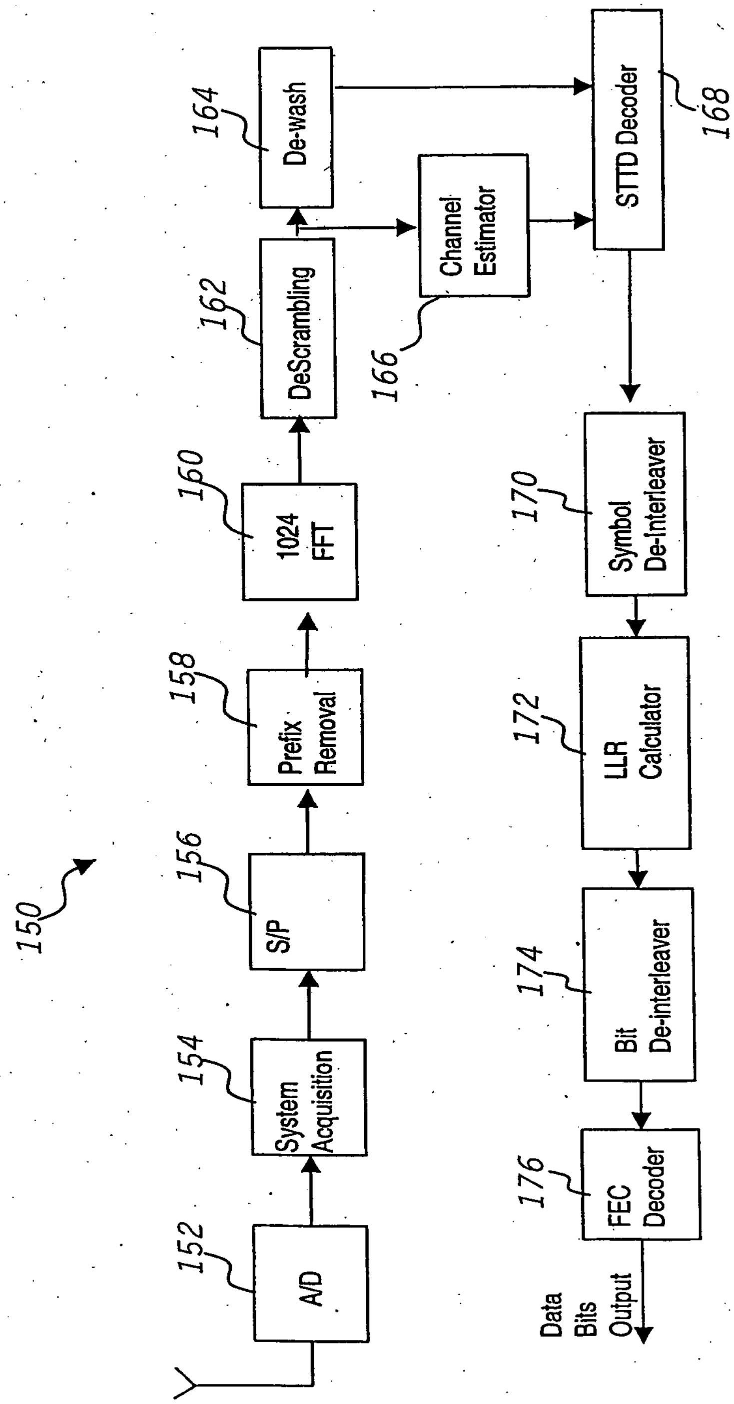

150
152
A/D
154
System Acquisition
156
S/P
158
Prefix Removal
160
1024 FFT
162
DeScrambling
164
De-wash
166
Channel Estimator
168
STTD Decoder
170
Symbol De-Interleaver
172
LLR Calculator
174
Bit De-interleaver
176
FEC Decoder
Data Bits Output

Fig. 9

INTERNATIONAL SEARCH REPORT

International Application No
PCT/CA 02/01119

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 H04B7/26 HQ4J13/02 H04L5/02 H04L27/26

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 H04B H04J H04L

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, WPI Data, PAJ, INSPEC

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	NORTEL NETWORKS, WAVECOMM, FRANCE TELECOM: "Stand-alone DSCH principles and benefits" TSR-RAN WORKING GROUP 1 MEETING #19, HTTP://WWW.3GPP.ORG/FTP/TSG_RAN/WG1_RL1/TSGR1_19/DOCS/PDFS/R1-01-0290.PDF, AVAILABLE FROM 23 FEBRUARY 2001, 27 February 2001 (2001-02-27) - 3 March 2001 (2001-03-03), pages 1-3, XP002219118 LAS VEGAS, USA the whole document --- -/--	1-19

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
4 November 2002	18/11/2002

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Chauvet, C

International Application No
PCT/CA 02/01119

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication,where appropriate, of the relevant passages	Relevant to claim No.
X	WAVECOM, FRANCE TELECOM, NORTEL NETWORKS: "Stand-alone carrier - A high speed channel in downlink" TSR-RAN WORKING GROUP 1, HTTP://WWW.3GPP.ORG/FTP/TSG_RAN/WG1_RL1/TSGR1_19/DOCS/PDFS/R1-01-0291.PDF, AVAILABLE FROM 23 FEBRUARY 2001, 27 February 2001 (2001-02-27) - 3 March 2001 (2001-03-03), pages 1-11, XP002219119 LAS VEGAS, USA the whole document ---	1-19
A	WO 01 35563 A (SAMSUNG ELECTRONICS CO LTD) 17 May 2001 (2001-05-17) the whole document -----	1-19

INTERNATIONAL SEARCH REPORT
Information on patent family members

International Application No
PCT/CA 02/01119

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO 0135563 A	17-05-2001	EP 1142177 A1 WO 0135563 A1	10-10-2001 17-05-2001